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Fiber Optic Cable Feedthrough and Sealing

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The development effort was accomplished by LiteCom, Inc. for NASA Lewis Research Center, Cleveland, Ohio, under contract no. NAS3-26611. The principal investigator was Robert J. Fan of LiteCom, Inc. Funding for this effort was through the Small Business Innovative Research (SBIR) program. The NASA Contracting Officer's Technical Representative was Amy Jankovsky. LiteCom expresses appreciation for technical guidance and assistance from NASA's Ms. Amy Jankovsky and other NASA personnel involved in this hermetic fiber-optic feedthrough development.

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Fiber Optic Cable Feedthrough and Sealing

Final Summary Report
8 April 1992 through 7 April 1994

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FOREWORD

This report summarizes the Phase II development effort for fiber optic hermetically-sealed feedthrough units. The major contract effort included design, development, evaluation, fabrication, testing and delivery of a prototype fiber optic hermetically-sealed feedthrough. Research in basis areas of technology was conducted, conclusions drawn and prototypes built to enable evaluation through observation, test and analysis. The areas researched in the Phase I design and associated testing were applied to further development in this Phase II effort. Emphasis has been placed on recognizing areas of improvement over existing hermetic sealing technology especially for fiber optics. Tests and evaluations were conducted to verify the design.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

SYMBOLS

1. C : Centigrade (Celsius)
2. CO_2 : Carbon Dioxide
3. Co : Cobalt
4. Db : Decibel
5. ° : Degrees
6. F : Fahrenheit
7. He : Helium
8. ^ : indicates exponent
9. Khz : Kilo-hertz (10^3 hertz)
10. KM : Kilo-meters
11. Kpsi : 10^3 pounds per square inch
12. Megarad : 10^9 rads
13. u : 10^{-6}
14. um : 10^{-6} meters
15. nm : Nano-meters (10^{-9} meters)
16. n/cm^2 : Newton per square centimeter
17. Nd : Neodymium
18. Ne : Neon
19. Nw : 10^{-9} Watts
20. Si : Silicon
21. W : Watts
22. λ : Wavelength

ABBREVIATIONS

1. Attn : Attenuation
2. cc : Cubic Centimeters
3. E/B : Ensign-Bickford Co.
4. He : Helium
5. IR : Infra-red
6. Min : Minute
7. PCS : Plastic-Clad Silica
8. Rads : Unit of radiation
9. Sec : Seconds
10. telecom : Telecommunications
11. UV : Ultra-violet
12. vs : versus
13. VSC : Raychem high performance fiber optic cable
14. Z-number : Atomic number in periodic table

ACRONYMS

1. APD : Avalanche Photodiode
2. DoD : Department of Defense
3. HCS : Hard Clad Silica
4. NASA : National Aeronautics and Space Administration
5. SBIR : Small Business Innovative Research
6. S-CUBED : A Division of Maxwell Laboratories, Inc.
7. Qhe : Helium Leak Testing, Inc.

Executive Summary

Feedthrough units were developed which sustained cryogenic (-196°C) to elevated (+200°C) temperatures while maintaining 10^{-11} cc/sec He leak rate. Program accomplishments include a comprehensive review and evaluation of component elements of hermetic feedthroughs. These components were optical fibers, sealing materials, feedthrough housings and backshells. Final component selection was based upon findings of the Phase I research effort and more focussed research in initial stages of Phase II effort. The component research was then used as a basis for design of feedthrough and backshell units, fabrication of test items and comprehensive evaluation/performance testing of developed feedthroughs. Testing of the feedthrough units included mechanical and environmental testing with pre and post leak rate and signal transmission level monitoring. Appendix F shows the program Work Plan. Appendix A presents the Final Test Report with summary data and discussion of results.

1.0 Introduction

1.1 Scope

Specific tasks which were planned and carried out in the Phase II SBIR development program are listed below:

- Task 1 - Development and Refinement of Sealing Concepts
- Task 2 - Feedthrough Development/Design
- Task 3 - Backshells Development
- Task 4 - Fabrication and Assembly
- Task 5 - Tests and Evaluation
- Task 6 - Radiation Hardening Testing
- Task 7 - System Design and Specifications
- Task 8 - Management and Documentation

The program accomplished the goals of defining the best component elements of feedthroughs and verifying superior performance through construction of prototypes and comprehensive testing of the prototypes. Testing was in signal performance with insertion loss and change in optical transmittance while undergoing the following; in mechanical stability with Sinusoidal, Random Vibration and Mechanical Shock tests, in environmental stability with Salt Spray, Thermal Shock and Humidity tests, and in exposure to Neutron Fluence Radiation, Gamma Radiation and Ion Radiation tests.

1.2 Objectives and Approach

The objective of this contract effort has been to develop the technology needed for a fiber optic cable feedthrough especially applicable to harsh environments such as encountered by the Space Shuttle main engine. A conceptual design for the fiber optic cable feedthrough consisting of the sealing device, fiber optic feedthrough unit, and ruggedized backshells was first fully prepared. The major effort of the contract has been to design, develop, fabricate, test, evaluate, and deliver prototype fiber optic feedthroughs and sealing devices which are hermetically sealed and can be used on a rocket engine controller interface. The performance of the feedthrough and backshell have been assessed and documented with accelerated environmental and mechanical testing.

1.3 Background

The measurement of cryogenic liquid propulsion systems with reliable, safe sensing technology has been of great interest to many researchers and engineers in recent years. New advances in the areas of combustion technology, and high temperature metallurgical and chemical processes power generation equipment, nuclear energy systems, weapons, space applications and similar areas have established a need for development of a highly accurate, high resolution, high temperature and high pressure feedthrough unit. Optical fiber feedthrough technology provides such a means. These feedthroughs are particularly useful because they are free from the interference effects caused by strong nuclear and electromagnetic radiation fields.

Military systems must survive the adverse nuclear environment induced by tactical/strategic weapons, harsh environment and harsh mechanical conditions.

Commercial systems must survive adverse environments in space (or artificial satellites), on the ocean floor, in vessels with nuclear power engines and in nuclear power plants. Systems exposed to radiation fields are no exception where the advantageous features of lasers/fibers are widely used.

Radiation exposure can be categorized as transient (EMP, ionized nuclear weapon effect) or continuous long-term (space, nuclear power, etc). One of the most adverse environments is the space environment which is effectively long-term radiation exposure. Optical fibers and feedthroughs directly exposed to the rays of the sun can experience temperatures higher than

150°C, and when away from the sun's rays can experience temperatures as low as -150°C. Besides the natural spaceborne radiation environment, which can average around 1 rad (si) per day, a military spacecraft may be required to tolerate much higher levels of radiation exposure. The combined hostile environment of temperature fluctuation and radiation exposure can have adverse effects on optical fibers and feedthroughs, as well as traditional electronic components.

Exposure to extreme pressure differentials requires high hermetic sealing capability where optical fibers pass through the pressure differential barrier.

Influence of radiation on mechanical and signal transmitting properties of optical fibers, cables, feedthroughs, and sealing are concerns in building a more-reliable fiber optics sensor system. Fiber coatings and fiber sealing play a significant role in space applications due to temperature and outgassing influences. A wrong coating and inadequate sealing may cause increased microbending losses during temperature cycling. In addition, the coating and sealing may chemically deteriorate and produce a film over a space shuttle optic channel due to outgassing. This outgassing process, combined with the temperature extremes and the radiation environment of the space shuttle, complicate the selection of fiber, design of feedthrough and sealing units.

Fiber optic feedthrough research, design and limited testing were carried out in Phase I of the Fiber Optic Cable Feedthrough and Sealing NASA Contract NAS3-26240. This research effort was conducted to investigate improved means of providing reliable fiber optic cable feedthrough sealing and temperature withstanding capability in high temperature exposure, low temperature (cryogenic) exposure, high pressure and severe vibration conditions.

NASA has interest in research of fiber optic technology in cryogenic liquid propulsion systems environment. High and low temperature extremes in space applications demand highly ruggedized and reliable fiber optic feedthroughs.

In Phase I, state of the art information was sought and documented regarding potential fibers and potential hermetic sealing of materials. Fibers were evaluated and the most promising candidate fibers for feedthrough applications were selected. Limited tests were carried out on selected fiber samples. A design of a prototype feedthrough unit was developed, prototypes fabricated and tested at assembly for optical insertion loss. A helium leak-rate test was conducted at 10^{-9} for a polycrystalline feedthrough material. Another helium leak-rate test was conducted at 10^{-8} for zircon silicate feedthrough material. Temperature testing on fiber/feedthrough units was conducted up to 1040°F. Results are reported and were promising for particular fibers and feedthrough materials. Cryogenic low temperature testing was also conducted at -320°F (liquid Nitrogen) on the prototype feedthrough units with a duration of 3 days. High performance results were obtained with Titanium-Carbide sealed fibers and aluminum-coated fiber. After feedthrough materials were evaluated, best results were obtained with polycrystalline and zircon silicate materials. Backshells were designed to provide for the requirement of ruggedized fiber optic cabling as an option on one or both sides of a bulkhead barrier.

This technology is potentially useful in a wide variety of military and commercial applications including but not restricted to space vehicles, launchers, aircraft, mines, ships, submarines, nuclear power plants, refineries, medical use, storage, transportation and telecommunications.

2.0 Technical Approach and Results

The goal of this Phase II SBIR contract effort has been to develop the technology needed for fabricating extreme pressure differential, extreme temperature range fiber optic hermetic feedthrough units. This development was directed towards producing a fiber optic cable feedthrough especially applicable to harsh environments such as encountered by the Space Shuttle main engine. A conceptual design for the fiber optic cable feedthrough consisting of the sealing device, fiber optic feedthrough unit, and ruggedized backshells was prepared. The major accomplishments of the effort have been to design, develop, fabricate, test and evaluate a prototype fiber optic feedthrough and sealing device which is hermetically sealed and can be used on a rocket engine controller interface. The performance of the feedthrough and backshell have been documented with optical monitoring during accelerated environmental and mechanical testing including thermal shock, helium leak, salt spray, humidity, space radiation, mechanical shock and vibration loading conditions.

The tasks of the program, as outlined in 1.1 are reviewed in the following portion of the report with summary information presented for program design, development and testing as applicable. A summary of results and conclusions follows.

2.1 Task 1 - Development and Refinement of Sealing Concepts

2.1.1 Objectives and Approach

To obtain a hermetic sealed feedthrough, the sealing materials and techniques must be established. Various state-of-the-art sealing materials were compared for ability to provide a high-grade hermetic seal with aluminum and to hermetically seal to optical fibers.

The sealing to aluminum is not a trivial matter, since aluminum has a relatively high coefficient of thermal expansion and we are working with a broad temperature range of -196°C to +200°C. Aluminum was a preferred material because of ease of machining, light weight and availability. However, most hermetic sealing materials have a low tolerance to thermal expansion and contraction of the components which they are sealing. Thus, the best sealing material was essential to successful hermetic sealing between the optical fibers and the aluminum housings.

Many fibers are available which appear to be suitable candidates for hermetic sealing since they have coatings which are integral to the fiber. If these coatings are of materials likely to be hermetically sealed, they should withstand the broad temperature range and assure sealing through the environmental and mechanical tests.

2.1.1.1 Assessment and Design

The first portion of the effort had to do with assessing what sealing techniques and materials are current state-of-the-art in usage. Technology assessment resulted in a review of relative merits of sealing material, housing material, fibers, buffers, coatings, terminus materials and expectations of sealing capabilities.

2.1.1.2 Fiber Analysis

Fiber analysis and research was a continuation from the Phase I work and revealed that titanium-coated fiber was no longer available. Platinum-coated fiber was considered as was carbon-based hermetic coated fiber, polymeric coatings and other non-metallic coatings.

The major functions of fiber coatings are: protection from external abrasion and the environment, and strength preservation. Three major coatings, polymeric, metallic, and non-metallic, are commonly used on fibers. No single coating can fulfill all mechanical, optical and environmental requirements.

Polymeric coatings, such as UV-cured acrylate, silicone, and polyimide, have limited applications at high temperatures. UV-cured acrylate coatings, which are the most commonly used type in the fiber optic industry, can withstand temperatures up to 100°C, whereas silicone and polyimide can withstand temperatures up to 200°C and 350°C, respectively. Metallic coating, such as aluminum, gold, platinum and titanium-carbide, usually can stand higher temperatures, but due to the high Z number in the periodic table, thermal stability and chemical resistance prevent most of these coatings for high orbit space applications. Due to excellent thermal stability and chemical resistance, a polyimide coating or an aluminum coating is preferred on optical fibers for high temperature (375°C) applications.

Specific fibers were reviewed with LiteCom evaluation of eight parameters to compare relative characteristics. The eight fiber parameters were:

* Core Diameter (100/140);
* Numerical Aperture;
* $NA = n_o\sqrt{2\Delta}$
* Index Profile Parameter α ;
* $n^2(\rho) = n_o^2 - NA^2\rho^\alpha$
* Core Index and Derivatives;
* Index Difference and Derivatives;
* Length;
* Mode coupling and Attenuation Parameters;
* Leaky Modes.

Hermetic sealing characteristics and fiber optical characteristics were researched. Results of this research are summarized for the hermetic coating, effect of radiation on fiber and temperature considerations.

Hermetic Coating

Hermetic coating preserves the mechanical and optical performance characteristics of optical fibers. Moisture (water) vapor can penetrate conventional organic polymer coatings, resulting in stress corrosion and microcrack growth. Fiber reliability and service life are adversely affected. A related problem is the presence of hydrogen molecules in certain cabling materials. They can penetrate the fiber core, causing increased attenuation. Through out the literature studies and conversation between LiteCom and fiber manufacturers, we found that the carbon base, hermetically coated fiber does not fatigue during long-term storage, active use or prolonged exposure to moisture. Therefore, using a hermetic coating is advisable.

Radiation Hard Fiber

Radiation can penetrate the core of optical fiber, causing an increase in attenuation which may interrupt communications. The radiation hard optical fiber was selected to resist radiation, ensuring accurate, uninterrupted communications in the vicinity of a controlled radiation source or nuclear event. Task 4 radiation hardening test will evaluate the fibers and feedthroughs in the various kinds of radiation environments.

High Temperature Buffer Coating

Conventional, acrylate-base, coated fiber withstands ambient temperatures up to 80° C. Polyimide coating, significantly extends that operating range. In temperatures as high as 375° C, polyimide coating preserves the outstanding optical performance and rugged mechanical characteristics of optical fiber.

Combining radiation hard optical fiber with carbon base hermetic coating and high temperature polyimide buffer is ideal for space shuttle Main Engine environment applications. LiteCom included the radiation hard fiber with metallic hermetic coating in the sealing material evaluations.

2.1.1.3 Sealing Material Search and Comparative Assessment

Sealing material search took place with a review of what hermetic sealing compounds are available and a comparative assessment of relative performance. Also, techniques of pressing/filling processes took place.

The sealing material generally determined to be best is the family of polycrystalline compounds. Evaluation of which formulation of polycrystalline material is best was conducted.

Five areas reviewed included:

1. Define Properties of Polycrystalline Ceramic Material:
   (a) physical characteristics;
   (b) thermal characteristics;
   (c) electrical characteristics
   (d) mechanical characteristics
   (e) time, temperature and environmental effects related to characteristics;

2. Processing of Polycrystalline Ceramics:
   This is an explanation of how polycrystalline ceramic material is initially processed to then use for sealing applications.

3. Techniques for Pressing/Filling Processes:
   This is a study of the techniques used for pressing polycrystalline ceramic powder into a cavity which is between the optical fiber and a metallic or composite housing in a hermetic sealing application.

4. Theory of Sintering (Sealing Techniques)

5. Design Considerations:
   Discussion of geometry, number of fibers, variations of feedthrough configurations.

2.1.1.3.1 Define Properties of Polycrystalline Material

Physical, thermal, electrical and mechanical characteristics were evaluated to assist in selection of the best sealing materials for fiber optic hermetic sealing.

For physical characteristics, density and bulk density were evaluated with research including use of SEM (Scanning Electron Microscope) cross-section photo micrographs. Thermal characteristics considered included thermal conductivity and coefficient of linear expansion. Electrical characteristics included dielectric strength or electrical resistance. Mechanical characteristics included stress, strain, modulus of elasticity, compressive strength, hardness, flexural strength and Poisson's Ratio. Time, temperature and environmental effects related to characteristics were evaluated with consideration of creep, corrosion, erosion and impact.

2.1.1.3.1.1 Physical Characteristics

<u>**Density**</u>

A theoretical measure of the mass per unit volume that is studied in units of grams per cubic centimeter (gm/cc^3) or pounds per square inch (psi). Porosity is assumed to be zero for theoretical purposes.

Bulk Density

The measured density of a polycrystalline ceramic body which includes all molecular crystal structure lattice defects and fabrication porosity. Bulk density defect effects can be observed in SEM (Scanning Electron Microscope) cross-section photomicrographs. The bulk density value is the actual, practical "real world" measured density of a material.

Porosity increases oxidation or corrosion and decreases strength, elastic modulus and thermal conductivity. Porosity decreases hermetic sealing capability. Table 1 shows bulk density of various polycrystalline and metallic materials.

TABLE 1

Density of Polycrystalline Ceramic and Metallic Materials

Material	Composition	Bulk Density (g/cm^3)
	Polycrystalline Ceramic materials	
Aluminum oxide	Al_2O_3	3.95
Beryllium oxide	BeO	3.06
Mullite	$Al_6Si_2O_{13}$	3.23
Magnesium oxide	MgO	3.75
Silicon carbide	SiC	3.17
Quartz	SiO_2	2.65

2.1.1.3.1.2 Thermal Characteristics

Thermal characteristics are being reviewed for the various candidate sealing materials and housing materials.

Thermal Conductivity

Thermal conductivity is defined as the rate of heat flow through a material and is reported in units of cal/sec - cm^2 - °C - cm, where calories are the amount of heat, cm^2 is the cross section through which heat is traveling, and cm is the distance the heat is traveling.

Coefficient of Linear Thermal Expansion

This is defined as an increment of length in a unit of length for a rise in temperature of 1°.

These properties will influence choice of materials for fiber optic hermetic sealing.

2.1.1.3.1.3 Electrical Characteristics

Dielectric Strength

Dielectric strength is the capability of the material to withstand an electric field without electrically breaking down and allowing electrical potential to pass through the material. Dielectric refers to the polarization that occurs when the material is placed in an electric field. Polycrystalline ceramics are very resistant to the passage of electricity, therefore, they make good insulators. Different applications require different characteristics. Titanium-carbide fiber feedthroughs must have relatively high strength, chemical resistance, and electrical resistance, but also must have high thermal conductivity. The high thermal conductivity is required to remove heat built up by SSME (Space Shuttle Main Engine) or other space vehicle applications. For this reason, polycrystalline ceramic Al_2O_3 base sealing material works best and is preferred for use with titanium-carbide fiber feedthroughs and also most likely with other hermetically coated fibers. The hermetic coated fiber and polycrystalline materials selected in this study for hermetic feedthroughs were reviewed for dielectric characteristics.

2.1.1.3.1.4 Mechanical Characteristics

Stress

A load that is applied to a material causing deformation and is reported in pounds per square inch (Psi) or megapascals (MPa). This can be either tensile or compressive.

Strain

The deformation of a material caused by stress, usually measured in inches per inch of elongation. This can be either tensile or compressive.

Young's Modulus (Modulus of Elasticity)

The proportionality constant between elastic stress and elastic strain or the amount of stress required to produce strain.

$$\text{Young's Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

The Young's Modulus was evaluated for fiber, sealing and housing materials selected. This was accomplished to assure that materials when used together are not being used beyond the appropriate limits.

Compressive Strength

The crushing strength of a material.

The compressive strength of a polycrystalline ceramic material is usually much higher than the tensile strength so it is beneficial to design a polycrystalline ceramic sealing feedthrough so that it supports heavy pressure loads in compression rather than tension. Table 2 shows relative hardness, calculated compressive stress and measured compressive stress.

TABLE 2

Comparison of hardness and Compressive Strength for Polycrystalline Ceramic Materials

	Vickers hardness		Calculated stress Hv/3 Yield		Measured Compressive strength	
Material	kg/mm^2	kpsi	kg/mm^2	kpsi	kg/mm^2	kpsi
Al_2O_3	2370	3360	790	1120	650	
BeO	1140	1620	380	540	360	
MgO	660	930	220	310	200	
$MgAl_2O_4$	1650	2340	550	780	400	
ZrO_2(+CaO)	1410	1980	470	660	290	
SiC	3300	4680	1100	1560	-	
Diamond	9000	13780	3000	4260	910	
B_4C	4980	7080	1660	2360	414	

Vickers Hardness

Determined by forcing a hardened sphere under a known load into the surface of a material and measuring the diameter of the indentation left after the test.

Vickers Hardness = imposed load/0.5393 (diameter of indentation)^2

$$[\ V = P/0.5393d^2]$$

The Vickers hardness values shown in Table 2 indicate relative hardness of the materials listed.

Flexural Strength

Flexural strength is defined as the maximum tensile stress at failure and is also known as bend strength or modulus of rupture (MOR). The flexure test is conducted by supporting a rectangular test specimen at both ends and applying a load either at the center (3-point loading) or at two positions (4-point loading), the load applied normal to the axis of the specimen. Table 3 lists relative flexural strength in terms of MOR for various polycrystalline and other ceramic material.

Poisson's Ratio

When a tensile load is applied to a material, the length of the sample increases slightly and the thickness decreases slightly. The ratio of the thickness decrease to the length increase is called Poisson's Ratio. Typically, Poisson's ratio is used to evaluate materials and can often be used as a comparison of material strength.

TABLE 3

Modulus of Rupture of Polycrystalline ceramic and Ceramic Materials

Material	MOR Mpa	MOR kpsi
Sapphire (single-crystal Al_2O_3)	620	90
Al_2O_3 (0-2% porosity)	350-580	50-80
Sintered Al_2O_3 (<5% porosity)	200-350	30-50
Alumina porcelain (90-95% Al_2O_3)	275-350	40-50
Sintered BeO (3.5% porosity)	172-275	25-40
Sintered MgO (<5% porosity)	100	15
Sintered stabilized ZrO_2 (<5% porosity)	138-240	20-35
Sintered mullite (<5% porosity)	175	25
Hot-pressed SiC (<1% porosity)	621-825	90-120
Sintered SiC (~2% porosity)	450-520	65-75
Reaction-sintered SiC (10-15% free Si)	240-450	35-65
Bonded SiC (~20% porosity)	14	2
Hot-pressed TiC	275-450	40-65

2.1.1.3.1.5 Time, Temperature, and Environmental Effects Related to Characteristics.

The deformation at a constant stress as a function of time and temperature. Creep is plastic deformation rather than elastic deformation and thus will not recover (spring back) after the stress is released.

Creep testing consists of measuring the deflection of the polycrystalline ceramic and other ceramic materials at a constant load and constant temperature.

Creep was investigated during material selection in feedthrough design.

Corrosion, Erosion, and Impact

(a) Ambient Temperature Corrosion

Strongly bonded ceramics have an excellent resistance to corrosion at room temperature. Polycrystalline ceramics and ceramics such as Al_2O_3 and Si_3N_4 are virtually inert to attack by aqueous solutions, including most strong acids and bases.

(b) Erosion

Erosion resistance of a material is determined primarily by the hardness of the material compared to the hardness of other materials with which it comes in contact.

Erosion can occur by sliding motion between two surfaces or particles between the surfaces. Sliding erosion (wear resistance) can be reduced by improving the surface finish of the ceramic.

TABLE 4

Erosion Resistance Versus Hardness

Material, in increasing order of Erosion Resistance		Hardness (kg/mm^2)
ZrO_2	(Zirconia)	1160
Al_2O_3	(Alumina)	2000
Si_3O_4	(Silicon Nitride)	2200
SiC	(Silicon Carbide)	2700
Diamond		7500

These characteristics were applied to any materials which are used in feedthrough applications designed with moving parts, such as coupling mechanism and mating/demating components.

(c) Impact

Defined as the application of a structural load to a material at a very high loading rate and usually to a localized area.

Polycrystalline ceramics and ceramics, because of their brittleness and low fracture toughness, cannot redistribute stresses due to impact; therefore, they are critically susceptible to impact damage.

In order to improve impact resistance the fracture toughness of the polycrystalline ceramic and ceramic must be improved. Two ways to improve fracture toughness are as follows:

Second - Phase Reinforcement:

Controlled dispersions induced into a second phase material can also improve material toughness and impact resistance. This method has been well demonstrated for tungsten carbide (WC) and titanium carbide (TiC) cements containing small quantities of metals such as nickel (Ni). The nickel was added or "controlled dispersed" in the formulation of the base material which was then heat treated as a second phase material.

LiteCom has evaluated the use of second phase reinforcement trace element additions to increase toughness and impact resistance.

Transformation Toughening:

This is defined as increasing the fracture toughness by dispersing particles of a material that undergoes a displacive transformation in a matrix or base material that does not go through the same transformation. During the cooling cycle, after initial sintering of the material, the dispersed particles undergo transformation which is accompanied by a volume change. The surrounding matrix material is cracked or stressed by this volume change causing a significant increase in the fracture toughness.

Most of the work on transformation toughening has been done with Zirconia (ZrO_2). (LiteCom has done investigative work with ZrS and ZrO_2 material in transformation toughening.) ZrO_2 undergoes a 3.25% volume expansion during cooling below 1000° C due to transformation from the tetragonal phase (a crystal system characterized by three axes at right angles of which only the two lateral axes are of equal significance and the third axis is of lesser significance) to the monoclinic phase (a crystal system characterized by three unequal axes with one oblique intersection).

This results in unstabilized zirconia and subsequent catastrophic failure of the part. Addition of CaO, MgO, or Y_2O_3 to the ZrO_2 results in a cubic crystal structure that is stable over the complete sintering process and does not undergo a phase transformation. This is referred to as stabilized zirconia which has improved toughness and impact resistance as compared with unstabilized zirconia.

However, stabilized ZrO_2 still has relatively low fracture toughness and poor resistance to impact. LiteCom has found that by adding insufficient amounts of CaO, MgO, or Y_2O_3 to stabilize the ZrO_2 completely and by careful control of particle sizing and processing causes a mixture of the stable phase and the unstable phase which results in high fracture toughness. This material is referred to as partially stabilized zirconia.

An increase in fracture toughness can also be achieved by extending the treatment of obtaining partially stabilized ZrO_2 to Al_2O_3 and Si_3N_4 and obtain partially stabilized Al_2O_3 and Si_3N_4 and other polycrystalline materials.

Thermal Shock

Thermal shock is defined as the thermal stresses that occur in a component as a result of exposure to a temperature difference between the surface and interior.

SiC has better thermal shock resistance than SiN, and partially stabilized ZrO_2 has excellent thermal shock resistance due to its high fracture toughness.

Partially unstable ZrO_2 and other partially unstable polycrystalline materials will be evaluated for superior thermal shock characteristics in hermetic fiber optic feedthrough applications.

2.1.1.3.2 Processing of Polycrystalline Ceramics and other Ceramics for hermetic sealing materials

Processing of polycrystalline ceramics for use as hermetic sealing materials included review of processing techniques for aluminum oxide powder, silicon carbide powder and silicon nitride powder. This information was useful in understanding the composition and forms available in hermetic sealing materials.

<u>Aluminum Oxide Powder</u>

Al_2O_3 powder is produced in large quantities from the mineral bauxite by the Bayer process. Bauxite is primarily colloidal aluminum hydroxide mixed with iron hydroxide and other impurities. The Bayer process involves the selective leaching of the alumina by caustic soda and precipitation of the purified aluminum hydroxide. The resulting fine-particle-size aluminum hydroxide is then thermally converted to Al_2O_3 powder.

Silicon Carbide Powder

Silicon carbide is produced by the Acheson process. The Acheson process consists of mixing SiO_2 sand with coke in a large elongated mound and placing large carbon electrodes in opposite ends. An electric current is then passed between the electrodes, heating the coke to about 2200° C. At that temperature the coke reacts with the SiO_2 to produce SiC plus CO gas. Heating is continued until the reaction is completed in the interior of the mound. The middle (core) of the mound contains SiC powder.

Silicon Nitride Powder

The two methods used to produce high-purity Si_3N_4 powder are the reduction of SiO_2 with carbon in the appropriate nitrogen environment and reaction of $SiCl_4$ or silanes with ammonia. Both of these methods produce very fine particle size. Si_3N_4 powder is not found naturally.

This information assisted in the understanding of the composition and the forms which are available of hermetic sealing materials.

2.1.1.3.3 Techniques for Pressing/Filling Processes:

Techniques for pressing/filling processes were reviewed to evaluate the most suitable means of actually utilizing the various polycrystalline compounds in the hermetic sealing of feedthroughs. Seven major techniques for compacting powder and forming desired preform shape configuration prior to firing are:

(a) uniaxial pressing (dry pressing)
(b) isostatic pressing
(c) hot pressing
(d) slip casting
(e) injection molding
(f) tape forming
(g) green machining

Of the techniques, uniaxial pressing (dry pressing) is favored by the LiteCom technical team because dimensional tolerances to ± 1% are normally achieved in routine applications. Closer tolerances can be achieved in special design. Dry pressing is more cost effective and easier to handle than other pressing/filling processes.

(a) Uniaxial Pressing (Dry Pressing)

Figure 1 shows mechanical press cycle. The pressed polycrystalline ceramic powder is formed in the preform which can be a single channel or a multi-channel disk (Figure 2 and 3). The preform is inserted between fiber(s) and metallic housing (Figure 4) before sintering which produces hermetical sealing. Controlling the portion of the polycrystalline powder into fill, we can anticipate the proper density or size. Some of the conditions that can be encountered with pressing are die wear and cracking; however, dry pressing achieves high production rates and close tolerances for our fiber optic feedthrough applications.

(b) Isostatic Pressing

Polycrystalline ceramic powder is enclosed in a liquid-tight rubber mold and immersed in a pressure vessel filled with fluid. Hydrolic oil or water is used. The fluid is pressurized, transmitting the pressure uniformly to all surfaces of the mold. The rubber deforms as the powder compacts, but springs back after the pressure is released and allows easy removal of the pressed part. Isostatic pressing is used for large parts that cannot be dry pressed.

(c) Hot Pressing

Pressure and temperature are applied at the same time. The advantages are reduced sintering (sealing) time, minimized porosity and higher strength.

(d) Slip Casting

Polycrystalline ceramic particles are suspended in water and cast (poured) into porous plaster molds. The mold extracts the liquid and compacted polycrystalline ceramic preform is formed along the mold walls.

(e) Injection Molding

Injection molding is a low-cost, high volume production technique. Injection molding is used extensively in the plastics industry. Polycrystalline ceramic preforms can be made with the same injection molding equipment, but with dies made of harder, more wear-resistant metal alloys. The polycrystalline ceramic powder is essentially added to the plastic as a filler. After injection molding the plastic is then removed by careful thermal treatments.

(f) Tape Forming

The doctor-blade process is used to form substrates. This process consists of casting a slurry onto a moving conveyor belt made of a thin sheet of Teflon or Mylar. The slurry is spread to a controlled thickness with the knife edge of a blade. The slurry is then dried resulting in flexible tape that can be stamped to the desired configuration prior to firing.

(g) **Green Machining**

Green machining is the machining of a polycrystalline ceramic preform before it has been fired or sintered. The preform at this point consists of compacted, loosely bonded powder and must be handled with great care because it is very fragile. Diamond tooling is not required; therefore, green machining is very economical.

2.1.1.3.4 Theory of Sintering

Sealing techniques or heat-sintering was reviewed. A review was made of an evaluation of the limitations of feedthrough components and of sealing compounds for the hermetic sealing process. Many sealing materials have unacceptable limitations. The objectives of sealing materials and methods are low sealing temperature and short sealing time. Also, there should be matched thermal coefficients, chemical resistance, no outgassing, and hermetic sealing between fiber and flange housing. In keeping with these parameters, heat control plays a major role in the hermetic sealing process.

A research effort feature of this by LiteCom, Inc. is the sealing of fiber to metal (aluminum) by proprietary techniques through the specialized sintering process and the unique chemical compound mix. At LiteCom, Inc., the densification of a polycrystalline ceramic preform is referred to as sintering which results in sealing. Heat is the energy used for sintering applications. Sintering is actually the removal of pores between preform particles accompanied by melting and shrinking of the polycrystalline ceramic material, combined with strong bonding and growth among particles.

Sintering creates a hermetic seal between the preform and the fiber surface as well as between the preform and the metallic housing. To do this, the polycrystalline ceramic powder is pressed into shape (preform) and inserted between fibers and metallic housing. Then, the unit is placed into a furnace and heated to melt the polycrystalline ceramic powder mixture. The resulting sealing material is basically a non-porous, polycrystalline ceramic composite that has a broad range of strength and elasticity, depending on the percent of Al_2O_3 used.

This review of sealing techniques provided the background for selecting the means of sealing the fibers into the housing in Type I feedthroughs and the means of sealing the fibers in the termini and the termini into the housings in Type II feedthroughs.

2.1.1.3.5 Design Considerations

The geometry and styles of feedthroughs under development included Type I feedthroughs with bulkhead mount to seal continuous fibers with or without protective backshells at fiber exit on one or both sides of the feedthrough and having one or a plurality of fibers in the feedthrough. Styles also under development include Type II feedthroughs with termini to provide connectorization on one side of the hermetic feedthrough and with or without backshell accessory option on the fiber entry side of the Type II feedthrough. These feedthrough configurations can be seen in Figures 5 and 6.

2.1.1.4 Sealing Material Mock-up Test

In order to evaluate sealing material, a "mock-up" test was conducted to perform trial sintering without making a full feedthrough model. A portable heat-producing unit was used which had a uniformity of heat output of ± 0.5%. This was beneficial for controlling the sintering temperature environment. Equipment was set up to conduct the study as shown in Figure 7. Fibers were first evaluated.

2.1.1.4.1 Fibers for Mock-up Test

NASA fiber/cables OC-1260 were given to us for evaluation. The visual results were as follows for various levels of heat exposure:

650°	coating material burned
590°	coating evaporated
240°	good and sealed

The polyimide buffer coating could only stand 390° C. Above that temperature, the material burned. (see Figure 8)

Next, gold fiber from Fiberguide Industries, 100/140 microns, was tested at 640°. The aluminum, V-groove melted and flowed along the gold fiber. As shown in the photos, the stress of the aluminum flowing broke the gold coated fiber. (see Figure 9, upper and Figure 10)

We ordered two kinds of fibers from Spectran Company. These were carbon based, hermetically sealed, and polyimide buffer coatings. These fibers were tested with sealing material. The specifications for the two kinds of fibers are as follows:

(a) SR-428-H Radiation Hard Optical Fiber (Step Index)

Core: 100.0 +/- 4 micrometers.
Clad: 140.0 +/- 3 micrometers.
Buffer: 170.0 +/- 5 micrometers.

NA: 0.24 +/- 0.02

BW: >/= 20 Mhz*km @ 850 nanometers

(b) SR-328-H Radiation Hard Optical Fiber (Graded Index)

Core: 100.0 +/- 4 micrometers.
Clad: 140.0 +/- 3 micrometers.

Buffer: 170.0 +/- 5 micrometers.

NA: 0.29 +/- 0.02

BW: >/= 100 Mhz*km @ 850 nanometers

Radiation can penetrate the core of optical fiber, darkening fiber dopant material and causing an increase in attenuation which may interrupt communications. The radiation hard optical fiber was selected to resist radiation, ensuring accurate, uninterrupted communications in the vicinity of a controlled radiation source or nuclear event. Later radiation hardening testing was conducted to evaluate the fibers and feedthroughs in various kinds of radiation environments.

(c) Spool #130 Hermetically sealed, Radiation Hard, Aluminum coated Optical Fiber (Graded Index)

Core: 100.0 +/- micrometers.

Clad: 142.0 +/- micrometers.

Buffer: 168.0 +/- micrometers.

NA: 0.29 +/- 0.02

BW: >/= 100 Mhz*km @ 850 nanometers

The test setup and vee-groove test block are shown in Figures 11 and 12.

2.1.1.4.2 Sealing Material

LiteCom received two sealing compounds from industrial IC package for our sealing material mockup testing efforts. Both compounds, Na_2O-BaO-SiO_2 and Na_2O-Al_2O_3-B_2O_3-SiO_2, consist of glass powder and special ceramic filler. This material is used for sealing ceramic IC packages, metal packages and fixing electronic parts. Mockup testing was done during this period.

One interesting response came from Nippon Electric Glass Co, Ltd. They were not able to offer any of their products that would comply with our requirements. Their FAX offered no alternatives. This company is one of the largest glass companies in the world, and they offered no product for achieving this design requirement.

2.1.1.4.3 Mockup Test

The sealing material mock-up testing was conducted to examine the hermetic sealing/bonding capability and signal transmission change effects of three types of fibers with two different sealing compounds. Each compound was used on a single aluminum V-groove block with a fiber laid through the compound.

Results of the two sealing compounds, Na_2O-BaO-SiO_2 and Na_2O-Al_2O_3-B_2O_3-SiO_2, tested during this period are shown in Table 5. Two compounds were tested six ways. Both compounds failed to meet the requirements. Compound number 1, Na_2O-BaO-SiO_2 with ceramic filler, was non-adhesive to the aluminum vee-groove. Compound number 2, Na_2O-Al_2O_3-B_2O_3-SiO_2 with ceramic filler, was brittle and only partially adhesive.

TABLE 5 - Sealing Material MockUp Tests

Compound	Temperature(°C)	Time(min.)	Fiber type
1	420	30	a
1	420	30	b
1	420	30	c
2	380	30	a
2	380	30	b
2	380	30	c

Additional sealing material was obtained and evaluated following the initial "Mock-up" test. This is reported in Task 2, paragraph 2.2

2.1.2 Results and Accomplishments

The exhaustive research and initial testing reported in Task 1 effort paved the way for further development leading to the final mature feedthrough configurations.

2.1.2.1 Fiber Findings and Recommendations

After review of many candidate fibers as reported, it was determined that polyimide coated fiber appears most promising for the temperature extremes and harsh conditions of the space shuttle engine proximity application. The polyimide buffer not only can withstand a broad range of temperatures, but it is readily bonded to hermetic sealing materials evaluated and maintains optical signal integrity. Other fibers which are viable candidates for hermetic sealing are the metallic-coated fibers, although the gold coated fiber proved to be too brittle for practical usage. The polyimide buffered fiber is also radiation-resistant, an important characteristic.

2.1.2.2 Sealing Material Findings and Recommendations

Exhaustive research into characteristics of sealing materials, processes of heat-curing and "mock-up" preliminary testing indicated that polycrystalline sealing materials offer great possibilities for hermetic sealing. Earlier Phase I testing indicated this and further testing reported in this Final Report shows that polycrystalline material is a superior hermetic seal material. Additional testing beyond the mockup test was conducted on several one-channel feedthrough prototypes as reported in paragraph 2.2.2.4. For sealing, the uniaxial pressing or dry pressing technique was preferred because dimensional tolerances can be routinely minimized to ± 1%. This process is also cost-effective and easy to handle.

2.1.3 Conclusions - Task 1

Various fibers, sealing materials and sealing techniques have been evaluated for suitability in providing hermetic sealing of optical fibers in aluminum housings. This evaluation has been necessary because to date, there has not been any successful hermetic sealing of glass fibers in aluminum housings which can maintain an extremely low leak rate even while exposed to wide variation in mechanical and environmental conditions. The analyses and searching in Task I has set the stage for advanced development, prototyping, testing and findings in the remaining tasks of this effort.

2.2 Task 2 - Feedthrough Development/Design

2.2.1 Objectives and Approach

Fiber optic feedthrough units which can maintain a pressure differential between vacuum and atmospheric pressure must be used in space applications. Task 2 was established to design feedthrough units which will meet the needs of various applications for space use. It was recognized that single channel fiber optic feedthroughs are useful either with or without strain relief and termination of ruggedized cable strength member and jacketing at the bulkhead penetrator. In other applications, multi-channel units are needed. Designs were initiated to enable use of both single channel and multi-channel technology. Another feature which could be very useful is to connect/disconnect a fiber optic line or cable assembly at a bulkhead. Investigation showed that a readily available, easy-to-use circular military/space grade connector was MIL-C-38999. This connector family with a series of different coupling mechanisms has been used either with a conventional knurled O.D. coupling plug shell or with special "wing nut" features proven useful for astronaut usage in a gloved, minimum dexterity situation, especially the MIL-C-38999 Series IV 90° quick coupling connector family.

Thus, feedthrough designs have been developed using single channel feedthroughs of LiteCom design and multi-channel feedthroughs for MIL-C-38999 Series III or IV connector interfacing. The designs have been developed as described in the following paragraphs.

2.2.1.1 Sealing Material Review

Following the Task 1 sealing material study and the limited results of the Task 1 "Mock-up" testing, additional sealing materials were evaluated. As work progressed, various formulations were tested and the polycrystalline compounds proved to be best for all requirements of the bulkhead feedthrough hermetic sealing application. Test results in 2.2.2.1 verify the levels of hermeticity satisfactorily reached using polycrystalline ceramic for sealing in aluminum housings.

2.2.1.2 Feedthrough Development - Type I and Type II

First, single channel feedthrough prototypes were designed as shown in Figure 13. Figure 13 shows the single channel design for hermetic bonding 10 prototypes. Ten prototypes were built for evaluation in leak rate testing. These prototypes have no flange mount feature for the evaluation testing. A flange feature was added in later design.

To fabricate the sealing prototype elements for single channel hermetic sealing, step holes were made inside tubing made of aluminum 6061-T6. The small close-fitting hole (a) is for the fiber passing through and the large hole (b) is for the sealing material preform which is pressed into place at room temperature with a light press fit.

This technique (uniaxial pressing) is more cost effective and this assembled single channel hermetic sealing unit is easier to handle than by using other pressing/filling processes. The sealing material preform of polycrystalline material is light-press-fitted into the large hole (b) of the modified 6061-T6 tubing for the later sintering procedure which takes place following positioning of the fiber in the sealing unit.

Ten single channel samples were made with four different fibers. The sintering temperatures were 240°C for all the samples with the duration of time at the sintering temperature of three minutes.

A cooling down rate of 40°C/min. followed the timed exposure to heat until the specimen was at room temperature. The cooling down rate was controlled by steps with a small cooling fan.

Ten single channel feedthroughs were measured for signal transmission levels before, during and after fabrication. Due to the low temperature sintering, the transmission loss was not significantly noticed.

The leak rate tests were conducted at a company, A-VAC Industries, in Anaheim, California. Final measured leak rate successfully passed is shown in Table 6. The samples, items 1 through 4, were light-press-fitted during the process of sealing materials. Items 5 through 10 were failed during the first sintering due to the sealing material without uniaxial pressing. But those items passed second sintering combined with light-press-fitting. The samples passed 10^{-9} cc/sec. and 10^{-10} cc/sec. which reached the limit of the measurement instrument in A-VAC Industries.

TABLE 6

Single Channel Feedthrough #	Sealing Material	First Sintering Temp. (°C)	Sintering Time (min.)	Fiber Type	Pressing	Helium Leak Rate (cc/sec.)	Second Simpering w/Pressing	Helium Leak Rate (cc/sec.)
1. LC-200-H9-01	Polycrystalline	240	3	Polyimide Step 100/140	Yes	1.0×10^{-10})		
2. LC-200-G2-01	Polycrystalline	240	3	Polyimide (Graded) 100/140	Yes	1.0×10^{-10}		
3. LC-200-AL-100-140	Polycrystalline	240	3	Aluminum Step 100/140	Yes	1.0×10^{-10}		
4. LC-G2LS-1401-01	Glass w/ceramic filler	400	60	Polyimide (Graded) 100/140	Yes	1.0×10^{-4}		
5. LC-200-GL-01	Polycrystalline	240	4	Gold Step 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}
6. LC-200-H9-02	Polycrystalline	240	3	Polyimide Step 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}
7. LC-200-G2-02	Polycrystalline	240	4	Polyimide (Graded) 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}
8. LC-200-AL-02	Polycrystalline	240	4	Aluminum Step 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}
9. LC-200-H9-03	Polycrystalline	240	3	Polyimide Step 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}
10. LC-200-G2-03	Polycrystalline	240	4	Polyimide (Graded) 100/140	No	1.0×10^{-4}	Yes	1.0×10^{-10}

Table 6 shows measured leak rate successfully passed (not to failure).

A multi-channel feedthrough was designed with the option available of conventional protective backshell hook-up to one or both sides of the feedthrough. This unit is seen in Figure 5, and a prototype was built. The design is based on the MIL-C-38999 Series III shell size 25 diameter and provides the standard MIL-C-38999 backshell accessory connecting threads, and serrated anti-rotating "teeth". Radiation hardened polyimide fibers were used in this 28 channel fabricated feedthrough.

Six out of 28 channels were measured for any change in optical signal transmission before, during and after hermetic sealing fabrication.

Figure 14 shows the test set-up for fabrication. Four channels were measured using an 850 nm LED source. Two channels were measured using a He-Ne laser light source. The transmissive signal did not change during this fabrication.

The unit described is a continuous fiber "Type 1" feedthrough. A "Type 2" feedthrough design was also made based on having continuous fibers permanently sealed into "pin termini" on one side of the bulkhead and with a connector interface for connect/disconnect capability on the other side of the bulkhead. This design can be seen in Figure 6. Standard size 16 MIL-T-29504/4 pin terminus style was chosen to mate with MIL-T-29504/5 socket termini in a mating plug connector half.

A Type 2 unit was constructed for evaluation.

The multichannel pigtail design feedthrough bulkhead receptacle chosen was a shell-size 13, Mil-C-38999 Series III or IV, 4-channel. The hermetic sealed receptacle contains pin termini which will mate with spring-loaded socket termini in the connector plug.

Techniques for fabricating the "type 2" pigtail style feedthroughs were evaluated. There are two basic approaches developed and prototypes of these were evaluated to determine the best sealing and the relative merits of fabrication.

In the first approach, termini are fabricated and hermetically sealed to prepared fibers using controlled melting temperature polycrystalline sealing material to bond fibers into the terminus ferrule. Meanwhile, a multichannel insert with terminus cavities is hermetically sealed into a feedthrough receptacle housing. Pigtailed termini tips are polished to assure low loss signal transmission in later mating to socket termini. The prepared pigtailed fibers are then positioned into the close-fitting cavities of the multichannel feedthrough insert and the termini are hermetically sealed in final position. Thus, there is hermetic sealing of fiber-to-terminus, of terminus-to-insert and of insert-to-housing.

In the second approach, the termini are again hermetically sealed to the fibers. Termini are polished to assure optimum signal transmission. Next, the prepared termini are positioned in the feedthrough insert and the loaded insert is then positioned in the feedthrough housing. Now, the entire unit can be fired to hermetically seal terminus-to-insert and insert-to-housing. The hermetic sealing material used to bond terminus-to-insert and insert-to-housing has a melt-point temperature low enough to assure the fiber-to-terminus bond is not disturbed.

When completed with either approach, the feedthrough is a bulkhead-mounting unit which will accept a mating fiber optic connector plug on one side. Fibers exit the other side of the feedthrough and can be either buffered fibers or single-channel fiber optic cables which are strength-member terminated to the hermetic feedthrough termini "tails."

For clarification, the following definitions describe the various types of feedthroughs.

Type I feedthrough:

Continuous fiber penetrates a bulkhead through a double-ended feedthrough which allows connection of backshells on both ends of the feedthrough.

Type II feedthrough:

Fiber is hermetically sealed in the pin termini which are hermetically sealed into a wall-mount receptacle or jam-nut mount receptacle. This will allow backshell protection of the fibers coming into the unit on one side, and plug connection of socket fiber optic termini on the other side of the feedthrough.

Type III feedthrough:

A short bulkhead penetrator with double-ended hermetically sealed pin-pin termini. The feedthrough has a receptacle interface on each side allowing plug connection of socket fiber optic termini on both sides of the feedthrough.

2.2.1.3 Terminus Development

Fiber optic termini to be used in the hermetic-sealed feedthrough application must be uniquely designed to provide required characteristics while allowing the options of buffered fiber termination or single channel fiber optic cable/strength member termination. Details of terminus construction were developed and are shown in Figure 15. Techniques for stripping the buffer coat of the fiber are being evaluated to assure the best preparation for the hermetic sealing operation. As shown in Figure 6, the terminus will be sealed into the insert. The terminus itself will have a precision tip which centers the bare fiber end precisely. This tip may be ceramic or stainless steel. Inside the ferrule, a portion of the bare, stripped fiber behind the precision tip will accept hermetic sealing material to bond the fiber in place. The remainder of the ferrule will be used to house the fiber and provide termination for either buffered fiber or the strength-member terminated single channel cable. The final feedthrough configuration as shown in Figure 6 enables a quick-connect with a fiber optic Mil-C-38999 Series III or Series IV mating plug connector half. Termination of the fiber or fiber/cable into the terminus includes hermetic sealing of the fiber plus use of standard military crimp tooling prior to hermetic sealing. Field crimp methods for the mating non-hermetic socket terminus were developed. This will assure user friendly, reliable assembly and provide a rugged crimped terminus. Final terminus preparation will require fiber-tip polishing using a polishing bushing and developed techniques.

Of the two methods to terminate pin termini for the Type II feedthrough, both will be acceptable fabrication techniques. Again, the first approach is to terminate using fiber with buffer stripped and the other approach is to terminate without stripping the buffer coat. Of the stripping methods, chemical stripping is acceptable for in-house feedthrough construction but not for in-field mating socket terminus construction. Both methods can employ mechanical or heat stripping. Spectran fiber with polyimide buffer can be held to 172 micron +.002/-.000. If it was decided to use fiber without removing buffer materials, cleaving through the buffer and fiber is a possibility.

The alignment bushing used to align pin terminus to socket terminus can have two variations evaluated. The first is shown at (A) in Figure 17. This is the standard split ceramic alignment bushing which applies equal radial forces on the termini tips unless one tip is slightly smaller than the other. In that case, there is a slight gap. However, the gap will only be as large as the tolerance range of tips. In the second variation shown in (B) of Figure 18, the alignment bushing has a configuration with one opening purposely slightly smaller (1 to 2 microns) than the other. In this case, the slight gap will again be a function of tip tolerance on the larger i.d. side since the smaller i.d. side is configured to provide a light press fit on that terminus tip.

In both cases, the gap is minimal and should have minimal impact on misalignment of the fiber cores. To select the better option, it is noted that the variation (B) is harder to clean if the tight i.d. side is more difficult to remove for through-cleaning of the alignment bushing. For this development program, the variation (A) will be used.

2.2.1.4 Test and Evaluation - Initial

Much testing was conducted to verify materials as reported and a leak rate test was conducted on a 28 channel Type 1 unit to verify sealing capability.

Results of this hermetic seal test performed on a prepared Type I, 28-channel fiber optic hermetically sealed feedthrough are shown in Figure 16. The test performed went to the extent of the capability of the machine, 6.75×10^{-8} cc/sec He at 72°F. A mass spectrometer was then used to detect any leakage and none was detected up to the limit of the detector.

Following this testing, additional units with various fibers were constructed and tested for hermeticity with positive results. The technique and materials for sealing were proving themselves. Fibers chosen for multi-channel evaluation included polyimide buffered aluminum-coated and gold-coated fibers.

Review of the two assembly methods for Type 2 feedthroughs were again made to evaluate the best technique for assembly.

Of the two methods previously discussed the first approach is best for use in this development effort. It is more simple for individual polishing. That method is to terminate the fiber into each pin terminus individually, sealing with hermetic bonding then polish the terminus tips to the final high quality finish desired. Following the completion of this procedure with all the termini for a feedthrough, they are all mounted in the insert, the insert mounted in the housing, and the hermetic seal applied to complete the bonding of termini-to-insert and insert-to-housing.

The second method will be more suitable for mass production where gang polishing with developed fixtures is more suitable. That method consists of constructing the feedthrough by locating fibers in the termini, locating termini in the insert, then curing the hermetic sealing material. The termini are all gang-polished at the same time which has the advantage of making all endfaces protrude the same distance from the front of the insert block. The final operation is to bond the insert into the housing with a second curing of the hermetic sealing material, this time between housing and insert. The two methods can be equally satisfactory since any difference in protrusion length of the termini in the first approach are accommodated by complementary retraction of spring-loaded termini.

2.2.2 Results, Accomplishments and Conclusions

Feedthrough units were constructed based on Task 1 research using the best materials and processes. Initial test results showed excellent withstanding of pressure differentials to the limits of the helium leak rate equipment of 10^{-10} cc/sec He.

Based on the results, the materials for sealing including aluminum housings, polyimide buffered fiber and polycrystalline ceramic sealing material were finalized for construction of final comprehensive testing.

2.3 Task 3 - Backshell Development

In many applications, the optical fibers, whether single channel or multi-channel, must be ruggedized to sustain mechanically and environmentally harsh conditions. At the feedthrough, entry of fibers must be protected with strain-relief and physical limiting of access to the immediate area of the fiber entry to the hermetic sealing interface. At this point, the protective buffer coat, strength member and fiber optic cable jacketing are removed to enable proper hermetic sealing. The solution is to provide a rugged protective backshell housing.

Backshells to protect fiber entry into the rear of the feedthroughs were designed for Shell Size 11 (2-channel, Type I feedthrough) and Shell Size 13 (4-channel, Type II feedthrough). Backshells were designed in a straight configuration (both feedthrough types) and in a right angle configuration (Type II only).

Clamping means for fiber/cable at the rear of the backshell is provided by a pair of opposing "saddles" or by a tapered "squeeze" arrangement on a cable grommet. Both designs were initially pursued. Molded boot information was obtained. This is for use at the rear of the backshell after the cable is clamped and will provide additional strain relief for the fiber optic cables. Molded boot configurations have been determined and suitable heat shrinkable boots have been selected and ordered.

Heat shrink tubing conforming to military specifications has been selected and ordered for use in strain relief and protection in various places.

2.3.1 Backshell Requirements/Design

A design for backshell protection was initiated and the results are shown in Figures 19 and 20 for straight and right-angle configurations. The requirements of the backshells included strain relief, capture of strength members at the rear of the unit, a "service loop" chamber for relaxing the fiber from any tensile forces and physical confinement of fibers from external forces and influences. By designing the rear of the feedthroughs with threads and serration per MIL-C-38999, the backshells could be designed and ordered with connecting threads and freely rotating coupling attachment rings which are available for connector backshells. Grommet seals are included to seal the backshell and thus the rear of the feedthrough from environmental substances.

2.3.2 Strain Relief Requirements

Clamping means for fiber/cable at the rear of the backshell is provided by a pair of opposing "saddles" or by a tapered "squeeze" arrangement on a cable grommet. Both designs were considered. Molded boots used at the rear of the backshell after the cable is clamped, will provide additional strain relief for the fiber optic cables. Molded boot configurations have been determined and suitable heat shrinkable boots were selected.

2.3.3 Fabrication of Backshells

Once the designs were established, backshells were fabricated to use in the harsh environmental and mechanical testing. For purposes of testing, straight backshells were fabricated which could be used with both Type 1 and Type 2 feedthroughs. Figure 19 shows the design of the straight backshell.

2.3.3.1 Grommet Seal Material

A material review was conducted for the cable grommet seal to be used at the rear of one backshell configuration. This grommet will radially compress fiber cable jacketing at the entry to the rear of the backshell.

Seal material selected was specified to maintain elasticity from -150°C to +200°C. However, following tests it was noted that the strain relief failed to perform at cryogenic temperature due to hardening and embrittlement of the current materials. Special alternative silicone-based materials were tested and were found to remain reliable and provide necessary strain relief at very low temperatures (-150°C).

2.3.4 Results and Accomplishments

The need for backshells was established, designs were prepared and units fabricated for evaluation and testing. Units built included straight and right angle units. At receipt of the backshells from the supplier, it was recognized that the right angle units had an abrupt, sharp angular internal configuration and a second prototype design with a smooth interior construction was fabricated. This is more conducive to protection of the fibers within the backshell. The final units provided the protection desired for fibers in the test feedthrough assemblies constructed.

2.3.4.1 Backshell Weight Consideration

Another backshell issue is weight consideration. There has been much work done recently in the area of composite materials being used for both connector shells and housings and backshell accessory housings. LiteCom conducted an investigation into the comparative weights of aluminum backshells vs. composite backshells. Many materials have been used for composite construction and these were researched for the most appropriate candidates to use in fabricating fiber optic backshells for the feedthroughs under development in this program.

Evaluation took place on the strength and weaknesses between aluminum and composite backshell materials. The basic materials that were studied are PEEK, PEK and ULTEM. The aluminum compositions have greater durability and withstand the temperature excursions better than the composites evaluated. The primary advantage of the composites continues to be its potential weight savings, critical in flight applications. Several candidate composite materials exist which have some of the advantageous characteristics of aluminum.

However, evaluation of composite materials failed to reveal any pertinent data on the ability of composite materials to withstand cryogenic temperatures. It was found that the aluminum compositions have greater durability and withstand the temperature excursions better than the composites evaluated to date. Therefore, LiteCom ultimately decided to use the aluminum compositions for the backshell fabrication.

2.3.5 Conclusions - Task 3

Backshells were designed and fabricated in a configuration which was acceptable to provide physical protection, isolation of fibers from tensile loading, sealing of fibers at the rear of the backshell, straight or right-angle options and constructed of materials selected for strength yet light in weight. Tests reported in paragraph 2.5 show that the backshells successfully provided protection in the harsh environmental and mechanical testing conducted on the feedthrough units.

2.4 Task 4 - Fabrication and Assembly

Following the Phase 1 breadboard prototyping and testing, complete feedthrough units were designed including accessory protective backshells. The feedthroughs are categorized as Type I and Type II. Type I feedthroughs have continuous fiber through the unit with hermetic sealing around the optical fibers and within the feedthrough housing. Type II feedthroughs are constructed with each fiber terminated in a pin terminus so that one side of the hermetic feedthrough has continuous fibers while the other side of the feedthrough has a connector receptacle interface with hermetically sealed pin termini. The Type I feedthrough will accommodate protective backshells on both sides of the bulkhead while the Type II feedthrough accepts a backshell on one side and a mating connector plug for optical connections and disconnects on the other side. A description of these elements follows.

2.4.1 Fabrication/Assembly, Type I Feedthroughs

The first Type I feedthrough units to be constructed were single channel units using gold-coated, aluminum coated and polyimide buffer coated single fibers. These were constructed to enable conducting evaluation tests in vibration, thermal shock and radiation. These mechanical and environmental tests were planned to allow relative comparative performance of the feedthroughs constructed with the subject fibers. Leak rate testing followed the environmental and mechanical testing for evaluation.

Later, Type I multi-channel feedthrough units were constructed. These were 2-channel feedthroughs, constructed in accordance with the design as described in paragraph 2.2.1.2, and shown in Figure 21.

To make the feedthrough units, a jam-nut mounting housing was fabricated of aluminum. The design also has provision for wall-mounting with four corner holes to enable bolting the housing to the bulkhead. A groove is incorporated which will assure sealing of the housing to the bulkhead.

The fibers were prepared with stripping of buffer coat from that portion of the fibers to be sealed into the feedthrough. Polycrystalline ceramic was introduced around fibers which were positioned in the through-holes of the feedthrough. Heat was applied and the hermetic sealing took place. This was the same technology used previously to seal the fibers in single channel prototype units tested in leak rate testing and demonstrating successful hermetic sealing between fibers and the aluminum housings.

Three 2-channel Type I feedthrough units were constructed for relative performance, one with gold coated fiber, one with aluminum coated fiber and one with polyimide bulkhead fiber.

Other feedthroughs constructed in the Type I configuration included 28-channel units which were built to be subjected to helium leak rate tests and to demonstrate the use of protective backshells which gave strain-relief and tensile relief to the optical fiber cables passing there through.

2.4.2 Fabrication/Assembly, Type II Feedthroughs

Many lessons of effectively sealing various fibers into aluminum housings were learned working with Type I feedthroughs. The next step was to fabricate Type II feedthroughs which requires a particular set of conditions concerning termini. These termini must be properly positioned surrounding the fiber ends and maintaining a very controlled positioning. Termination of the pin termini tips must be done in a controlled manner since these are permanently located once the hermetic sealing material is set. Fibers were sealed into termini with hermetic sealing polycrystalline ceramic material.

2.4.3 Termini for Type II Feedthrough

Three different Type II 4-channel feedthrough termini-to-aluminum connector housing seals were completed. The units assembled included 4 channel feedthroughs, each feedthrough constructed with fibers having a particular coating. One 4-channel unit had gold-coated fibers, one 4-channel unit had aluminum-coated fibers and one 4-channel unit had polyimide-coated fibers. The fibers were first hermetically sealed into termini as described below.

During this period, evaluation units of fibers-to-termini-seal were completed using 3 different fibers. Included in this task were termini containing sealed fibers having gold coating, aluminum coating and polyimide coating (Figures 22,23 and 24). These fiber-to-terminus evaluation units were constructed and a helium leak test (to pass 10^{-11} cc/sec) was conducted successfully on these evaluation units. Termini were then polished and examined under a microscope (See Figure 25).

2.4.4 Backshells-Straight

The backshell designed for use with either Type I or Type

II feedthroughs was first designed in a straight configuration. Figure 19 shows this backshell with threads on a freely rotating captivated coupling ring to match the MIL-C-38999 type backshell accessory threads. This backshell has a central chamber or "service loop" area to allow freedom of the fiber, isolating any tensile forces from the rear entrance to termini or to continuous fibers. It also has a rear cable clamp and compressive sealing features to press radially on the cables in a controlled manner. Letter designated dimensions may be selected for the particular fiber/cable size, connector shell size, etc.

2.4.5 Backshells-Right Angle

Another backshell configuration was developed for applications where the cable must be routed to a side orientation upon exit from the backshell. A right angle backshell is shown in Figure 20. This backshell has many of the same features described in 2.4.3 for connector hook-up, fiber protection safety and cable clamping.

2.4.6 Results and Accomplishments

Backshells were designed and fabricated to complement the developed Type I and Type II feedthroughs. The backshells can be produced to accommodate different sizes of connector shells and the backshells offer significant protection to the optical fiber cables terminated in Type II units or passing through the Type I units.

2.4.7 Conclusions - Task 4

The backshells were designed and constructed to protect the fibers of the program feedthroughs. In the test results reported in later paragraphs, it can be seen that the backshells were successfully used to accomplish the desired protection.

2.5 Task 5 - Tests and Evaluation

2.5.1 Objectives and Approach

The performance of the feedthroughs and backshells were assessed and documented with accelerated environmental and mechanical testing including thermal shock, helium leak, salt spray, humidity, space radiation, and vibration loading conditions. The radiation testing is reviewed in paragraph 2.6, Task 6. All other tests are reported in this section, paragraph 2.5.

2.5.1.1 Test Units Constructed

Feedthroughs were fabricated using various types of optical fibers as described and subjected to optical, environmental and mechanical testing. These feedthroughs were fabricated at LiteCom, Inc. 8033 Remmet Avenue, Canoga Park, CA. 91304, CAGE No. OHO94.

Test Facilities

The testing described herein was conducted at the following locations:

(1) LiteCom, Inc.
8033 Remmet Avenue
Canoga Park, CA 91304

(2) National Technical Systems Testing Division
20988 West Golden Triangle Road
Saugus, CA 91350

(3) Rockwell International, Defense Electronics - Anaheim
3370 Miraloma Avenue
P.O. Box 3105
Anaheim, CA 92803-3105

(4) Maxwell S-Cubed Division
3398 Carmel Mountain Road
San Diego, CA 92121-1095

(5) Helium Leak Testing,

19438 Londelius Street

Northridge, CA 91324

Hardware Identification/Preparation

Two sets of feedthrough assemblies were prepared for the testing program. This enabled conducting lengthy testing simultaneously in the interest of time. Table 7 shows the construction of the test feedthroughs.

TABLE 7 <u>Feedthrough Test Units</u>

Ident. No.	Feedthrough Type	No. of Channels	No. of Channels Used	Fiber Type
C1	II	4	4	Polyimide Buffer
C2	II	4	4	Aluminum Coated
C3	II	4	4	Gold Coated
C4	I	2	2	Polyimide Buffer
A	I	2	1	Aluminum Coated
B	I	2	1	Polyimide Buffer
C	II	4	2	Gold Coated
D	II	4	4	Polyimide Buffer

2.5.1.2 Overview of Tests

Abstract of Testing and Results

The following is a brief summary of the testing performed on the feedthrough units and the results of the testing. Test sequence for feedthroughs C1, C2, C3, C4 (See Table

7) was Salt Spray, Sinusoidal Vibration, Random Vibration, Mechanical Shock, Thermal Shock, Humidity. Test sequence for feedthroughs A, B, C, D was Neutron Fluence Radiation, Gamma Radiation, Ion Radiation.

Helium leak testing for hermeticity was conducted after each environmental and mechanical test. All units passed the 10^{-11} cc/sec helium test applied in every case. Testing follows the plan set forth in LC-T-92-C027-TP "Fiber Optic Cable Feedthrough and Sealing Test Plan" Appendix 2, and this plan is referred to in the following summary.

2.5.1.3 Insertion Loss Testing (Ref. para. 2.2 of LC-T-92-C027-TP Appendix 2)

Requirement: Test the insertion loss of each feedthrough unit as it is constructed comparing the strength of optical signal before insertion of the feedthrough in the line with the strength of the optical signal after insertion of the feedthrough.

Results: Type I units (See Appendix 2, Fig. 1) were fabricated and the insertion loss measurements were taken in accordance with EIA/TIA-455-34. (See Appendix 2, para. 2.2) Loss results were negligible as would be expected since the fibers were never broken to install the Type I feedthroughs. Measured losses were -.02 max.

Type II units (See Appendix 2, Fig. 2) were fabricated and the insertion loss measurements were taken in accordance with EIA/TIA-455-34. (See Appendix 2, para. 2.2) Losses were measured and ranged from 0.5 to 0.8 dB. More detailed description of the insertion loss testing can be found in Appendix 4 "Evaluation Test Data Sheets."

2.5.1.3.1 Optical Monitoring (Ref. EIA/TIA-455-20, page 49 of Appendix 2)

Requirement: Measure change in optical transmittance during the environmental and mechanical testing in accordance with EIA/TIA-455-20.

Results: The optical signal strength was recorded during the testing of the feedthroughs. The Type I units exhibited essentially no change during the testing. Type II units exhibited 0.1 dB maximum degradation as a result of exposure to testing.

More detailed description of the change in optical transmittance can be found in Appendix 4 "Evaluation Test Data Sheets" for each of the environmental and mechanical tests.

2.5.1.4 Pressure Differential - Initial Leak Rate Testing (Ref. para. 2.3 of LC-T-92-C027-TP, Appendix 2)

Requirement: Test the leak rate of the fabricated feedthrough units in accordance with para. 2.3 of Appendix 2, Test Plan. Test before and after exposure to environmental and mechanical tests.

Results: Feedthrough units were checked for hermeticity with a helium leak rate test prior to any testing. The units A, B, C, D were tested in radiation and checked after all three radiation tests. The units C1, C2, C3 and C4 were tested in salt spray, vibration (Sinusoidal, then random), shock, thermal shock and humidity. Complete data recordings of leak rate testing are shown in Appendix 4.

2.5.1.5 Salt Spray (Ref. para. 2.8 of LC-T-92-C027-TP; Appendix 2)

Salt Spray testing was conducted on the test feedthroughs C1, C2, C3, C4 as described in Table 8. Testing was conducted as described in Appendix III, paragraph 5.1 of LiteCom report No. LC-T-94-C027-TR, "Fiber Optic Feedthrough and Sealing Evaluation Test Report."

Requirement: The developed feedthrough test units were evaluated for withstanding exposure to a salt spray environment. The exposure was made to both Type I and Type II feedthroughs. The test units were subjected to 96 hours of salt spray testing in accordance with MIL-STD-202, Method 101, Test Condition B, using a 5 percent by weight salt solution. Immediately after exposure, the exterior surface and the mating face of the test specimens were thoroughly washed with tap water. The specimen was then inspected with 4X magnification and showed no evidence of exposure of basis metal nor indication of corrosion products.

Results: Change in Optical Transmittance was monitored by recording 850 nm signal level before, during and after the salt spray test. Comparison was made between initial (pre-test) readings and subsequent readings.

TABLE 8 <u>Salt Spray Test Results</u>

Feedthrough Type	Avg. dB from initial	
	Mid-way	Final
I	+.04	+.02
II	0	0

Overall optical performance in salt spray testing showed an increase of +0.02 dB avg. for the Type I feedthrough and no change for the Type II feedthroughs as shown in Table 8. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following salt spray testing and units were successfully tested to 10^{-11} cc/sec helium levels.

2.5.1.6 Vibration Testing (Ref. para. 2.5.1 of LC-T-92-C027-TP; Appendix 2) and Sinusoidal (Ref. para. 2.5.2 of LC-T-92-C027-TP; Appendix 2).

2.5.1.6.1 Random vibration testing was conducted on the test feedthroughs C1, C2, C3, C4 as described in Table 9. Testing was conducted as described in Appendix III, para. 5.2 of Final Report LC-T-94-C027-TR.

Requirements: Test units were to withstand, without damage of any kind, the application of a random vibration spectrum of +6 dB per octave from 20 Hz to 100 Hz and 1.0 g^2/Hz from 100 Hz to 2000 Hz in each of 3 mutually perpendicular axes for not less than 7 minutes per axis.

Results: Change in optical transmittance was monitored by recording 850 nm signal level before, during and after the random vibration test.

Optical signal levels were recorded before, during and after the random vibration testing. Type I and Type II feedthrough test results are shown in Table 9.

TABLE 9 Random Vibration Results

Axis	Feedthrough Type	Avg. dB from initial	
		During Test	Post Test
x	I	0	-.01
y	I	0	0
z	I	0	-.01
x	II	-.01	-.02
y	II	+.01	0
z	II	-.01	0

Note: The gold fiber, being brittle, degraded and cracked during random vibration testing and was not included in the loss averages.

Overall optical performance in random vibration showed losses of -0.02 dB max. average change for Type II feedthroughs and -0.01 dB max. average change for the Type I feedthrough as shown in Table 9. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following random vibration testing and units were successfully tested to 10^{-11} cc/sec helium levels.

2.5.1.6.2 Vibration - Sinusoidal (Ref. para. 2.5.2 of LC-T-92-C027-TP; Appendix 2)

Vibration testing was conducted on the test feedthroughs C1, C2, C3, C4 as described in Table 10. Testing was conducted as described in Appendix III, paragraph 5.2 of Final Report LC-T-94-C027-TR.

Requirement: Test units were to withstand, without damage of any kind, the application of sinusoidal vibration, simple harmonic motion in 3 mutually perpendicular axes at a sweep rate of 1 minute per octave from 10 Hz to 2000 Hz to 10 Hz as follows:

A. 10 Hz to 55 Hz at 0.325 inch double amplitude displacement.

B. 55 Hz to 2000 Hz at 50 g's peak.

C. The sweep shall be performed three times in each of three mutually perpendicular directions.

Results: Change in optical transmittance was recorded during and after the exposure to sinusoidal vibration by comparing signal strength to pre-test recorded readings. Type I and Type II feedthrough test results are shown in Table 10;

TABLE 10 **Sinusoidal Vibration Results**

Axis	Feedthrough Type	Avg. dB from initial	
		During Test	Post Test
x	I	-.01	0
y	I	0	0
z	I	0	0
x	II	0	0
y	II	-.04	-.03
z	II	+.02	+.03

Note: The gold fiber began to exhibit erratic performance and later cracked in random vibration, so the readings have not been included in the averages of Table 10.

Overall optical performance in sinusoidal vibration showed losses of -0.04 dB avg. max. for Type II feedthroughs and -0.01 dB avg. max. for the Type I feedthrough as shown in Table 10. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following sinusoidal vibration testing and units were successfully tested to 10^{-11} cc/sec helium levels.

2.5.1.7 Mechanical Shock (Ref. para. 2.6 of LC-T-92-C027-TP; Appendix 2)

Mechanical Shock testing was conducted on the test feedthroughs C1, C2, C3, C4 as described in Table 11. Testing was conducted as described in Appendix III, paragraph 5.3 of Final Report LC-T-94-C027-TR.

Requirements: Test units were to withstand, without damage of any kind, 3 shocks (40 G's, 11$\pm$1 millisecond half sine) in each direction of 3 mutually perpendicular axes.

The forces were produced by securing

the connectors to a sufficient mass and accelerating or decelerating the assembly so that the specified force was obtained. Three shock pulses were applied in each direction of each of the three major axes. The cable was clamped to points that move with the feedthrough. A minimum of 8 inches of cable were unsupported behind the rear of each feedthrough.

The testing was conducted in accordance with EIA/TIA-455-14 "Fiber Optic Shock Test". Change in optical transmittance will be monitored by recording 850 nm signal level before, during and after the shock test.

Results: Change in optical transmittance was recorded for the mechanical shock test after completion of the test. The short time duration of the shock pulse made monitoring during the test impractical without sophisticated equipment. Type I and Type II test results are shown in Table 11.

TABLE 11 **Mechanical Shock Results**

Feedthrough Type	Avg. dB from initial
I	-.03
II	-.02

Note: The gold fiber in feedthrough C3 (Type II) was brittle and cracked during vibration testing. Readings for C3 feedthrough were not included in the averages of Table 11 results.

Overall optical performance after exposure to Mechanical Shock testing was -0.03 dB max. for Type I feedthroughs and -0.02 dB max. for Type II feedthroughs as shown in Table 11. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following mechanical shock testing and units were successfully tested to 10^{-11} cc/sec helium levels.

2.5.1.8 Temperature Cycling - Thermal Shock (Ref. para. 2.4 of LC-T-92-C027-TP; Appendix 2)

Requirement: Feedthrough test units C1, C2, C3, C4 per Table 12 were subjected to thermal cycling. The test units were subjected to the low temperature of -320°F (-196°C) for 30 minutes with a transition time of 5 minutes maximum for moving to the high temperature chamber. Soak time at high temperature of +392°F (+200°C) was 30 minutes. This constituted one complete cycle. Five complete cycles were conducted on each specimen. The test was conducted in accordance with EIA/TIA 455-3 (see para. 2.4 of Appendix 2).

Results: Change in optical transmittance was monitored before, during and after the test to indicate optical performance influence by the exposure to the varied thermal conditions. This was done in accordance with EIA/TIA-455-20 "Measurement of Change in Optical Transmittance." Optical signalling was at 850 nanometer during exposure of feedthroughs C1, C2, C3, C4.

During the 5 cycles, the following measurements were observed:

TABLE 12 <u>Thermal Shock Results</u>

Cycle No.	Cold Temp.(-320°F) From Initial (dB) Avg.		Hot Temp.(+392°F) From Initial (dB) Avg.	
	Type I (C4)	Type II (C1,C2,C3)	Type I (C4)	Type II (C1,C2,C3)
1	+.01	+.02	+.03	+.05
2	-.02	0	0	+.03
3	+.01	+.03	+.02	+.07
4	+.01	+.03	+.02	+.07
5	+.01	+.04	+.02	+.07

Post test comparison of the Type I feedthrough showed average change of 0 from initial readings taken prior to thermal shock testing. Post test comparison of Type II feedthroughs showed an average change of +.06 dB from initial readings taken prior to thermal shock testing.

Overall optical performance was excellent with all losses averaging under 0.1 dB change during thermal shock testing. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following thermal shock testing and units were successfully tested to 10^{-11} cc/sec helium levels.

There was another observation noted after thermal shock testing. The cables with hytrel buffer tubing had severe degradation of that buffer coat due to the heat applied. The optical fiber and signal was not impacted, and the units passed hermeticity testing to 10^{-11} cc/sec helium leak rate testing after thermal shock testing.

2.5.1.9 Humidity (Ref. para. 2.9 of LC-T-92-CO27-TP; Appendix 2)

Humidity testing was conducted on the test feedthroughs C1, C2, C3, C4 as described in Table 13. Testing was conducted as described in Appendix 2, para. 2.9.

Requirement: Type 1 and Type 2 feedthrough units were tested in a humidity exposure environment. The units were subjected to 240 hours of exposure to 98-100% humidity at 104°F (+40°C) to 140°F (+60°C). Prior to the humidity exposure, the specimens were conditioned.

A. Conditioning - Condition specimens at +45°C to +55°C (+113°F to +131°F) for 24 hours and return to room ambient temperature prior to beginning humidity exposure.

Measure and record optical transmittance at room ambient temperature before and after conditioning.

B. Exposure - Subject test items to the temperature and humidity conditions described above for 240 hours exposure. Measure and record optical transmittance before, during and after humidity exposure. Record at end of each 24-hour period.

Results: Change in optical transmittance was recorded for feedthroughs C1, C2, C3, C4 using 850 nm signals by comparing monitored readings during the humidity test and final readings to the initial readings. Type I and Type II feedthrough test results are shown in Table 13.

TABLE 13 <u>Humidity Test Results</u>

Feedthrough Type	Avg. dB from initial	
	Mid-way	Final
I	0	0
II	0	0

Note: Due to the C3 Type II feedthrough failure in vibration testing, it was not included in this humidity test. Instead, feedthrough C (which was one of the test units in radiation testing) was substituted.

Overall optical performance in humidity testing was excellent with negligible measured losses during and after the completion of testing. Complete data recordings are shown in Appendix 4. Leak rate testing (Appendix 4) was performed following humidity testing and units were successfully tested to 10^{-11} cc/sec helium levels.

2.5.1.10 Radiation Testing

The radiation testing conducted during this Phase II effort is reported in paragraph 2.6, Task 6 as a separate group of tests from the environmental and mechanical tests reviewed in paragraph 2.5, Task 5 "Tests and Evaluation".

2.5.1.11 Final Leak Rate (Pressure Differential) Testing

Hermeticity of all units was checked initially, prior to any testing both for set A, B, C, D (radiation testing feedthrough units) and for set C1, C2, C3, C4 (all other environmental and mechanical tests). The leak rate level of 10^{-11} cc/sec was checked again following every test. Always, the units passed this check including after the final test for each set of feedthroughs. This verifies that the hermeticity achieved in initial construction maintains integrity even after exposure to harsh mechanical and environmental testing.

2.5.2 Results and Accomplishments

As described in 2.5.1.11, the hermiticity of the developed, constructed and tested feedthroughs was proven to be maintained even after exposure to harsh testing. The optical signals were slightly affected by tests as shown in the results of Tables 7-13. The performance of the tests was intended to simulate conditions anticipated to be encountered in space use at cold (cryogenic) and hot (in proximity of rocket engine walls) conditions, in vibration, shock, humidity, salt spray expected either in-flight and/or while in earth storage.

2.5.3 Conclusions - Task 5

Hermeticity remains even after rigorous tests. Some observations follow. Through all these tests, the gold fiber appears to be too brittle to sustain the mechanical tests. The hytrel buffer tubing used to protect the fibers was unsuitable in the range of temperatures used. Another protective tube should be used where tubing is needed. The Brand Rex cable jacket performed well through all tests. This jacket material would be suitable for tubing (perfluoroalkoxy-PFA or fluorinated ethylene propylene-FEP). The polyimide fiber appears to be most useful in terms of performance without degradation in the mechanical, environmental and optical tests.

2.6 Task 6 - Radiation Hardening Testing

Radiation (Red. para. 2.7 of LC-T-92-C027-TP; Appendix 2)

2.6.1 Objectives and Approach

Radiation testing was conducted on the test feedthroughs A, B, C, D as described in Table 14. Testing was conducted as described in Appendix 2, para. 2.7. Three different types of radiation testing were performed. Neutron Fluence, Gamma, and Ion radiation. Hermeticity testing was conducted to evaluate performance of optical signal transmission and leak rate levels following the radiation testing.

2.6.1.1 Test Units Constructed

Two sets of feedthrough assemblies were prepared for the testing program. This enabled conducting lengthy testing simultaneously in the interest of time. Table 14 shows the construction of the test feedthroughs.

2.6.1.2 Overview of Tests

Abstract of Testing and Results

The following is a brief summary of the testing performed on the feedthrough units and the results of the testing. Test sequence for feedthroughs A, B, C, D was Neutron Fluence Radiation, Gamma Radiation, Ion Radiation.

Helium leak testing for hermeticity was conducted after each radiation test. All units passed the 10^{-11} cc/sec helium test applied in every case. Testing follows the plan set forth in LC-T-92-C027-TP "Fiber Optic Cable Feedthrough and Sealing Test Plan" Appendix 2, and this plan is referred to in the following summary.

2.6.1.3 Insertion Loss Testing (Ref. para. 2.2 of LC-T-92-C027-TP Appendix 2)

Requirement: Test the insertion loss of each feedthrough unit as it is constructed comparing the strength of optical signal before insertion of the feedthrough in the line with the strength of the optical signal after insertion of the feedthrough.

Results: Type I units (See Appendix 2, Fig. 1) were fabricated and the insertion loss measurements were taken in accordance with EIA/TIA-455-34. (See Appendix 2, para. 2.2) Loss results were negligible as would be expected since the fibers were never broken to install the Type I feedthroughs. Measured losses were -.02 max.

Type II units (See Appendix 2, Fig. 2) were fabricated and the insertion loss measurements were taken in accordance with EIA/TIA-455-34.

(See Appendix 2, para. 2.2) Losses were measured and ranged from 0.5 to 0.8 dB. More detailed description of the insertion loss testing can be found in Appendix 4 "Evaluation Test Data Sheets."

2.6.1.3.1 Optical Monitoring (Ref. EIA/TIA-455-20, page 49 of Appendix 2)

Requirement: Measure change in optical transmittance during the environmental and mechanical testing in accordance with EIA/TIA-455-20.

Results: The optical signal strength was recorded during the testing of the feedthroughs. The Type I units exhibited essentially no change during the testing. Type II units exhibited 0.1 dB maximum degradation as a result of exposure to testing.

More detailed description of the change in optical transmittance can be found in Appendix 4 "Evaluation

Test Data Sheets" for each of the environmental and mechanical tests.

2.6.1.4 Pressure Differential - Initial Leak Rate Testing (Ref. para. 2.3 of LC-T-92-C027-TP, Appendix 2)

Requirement: Test the leak rate of the fabricated feedthrough units in accordance with para. 2.3 of Appendix 2, Test Plan. Test before and after exposure to environmental and mechanical tests.

Results: Feedthrough units were checked for hermeticity with a helium leak rate test prior to any testing. The units A, B, C, D were tested in radiation and checked after all three radiation tests. Complete data recordings of leak rate testing are shown in Appendix 4.

2.6.1.5 Neutron Fluence Radiation (Ref. para. 2.7 of LC-T-92-C027-TP; Appendix 2)

Four fiber optic feedthroughs, A, B, C, D as listed in

Table 14, were neutron irradiated as described in Appendix 6 of LC-T-94-C027-TR. Testing was conducted at S-Cubed Radiation Facilities described in Appendix 5 of LC-T-94-C027-TR.

Requirements: Type I and Type 2 feedthrough units were to be exposed to the neutron irradiation for 6 hours at a target fluence level of $1x10^{12}$ neutron/cm^2. Test units were to be rotated at approx. 4 RPM during exposure.

Results: Change in optical transmittance was recorded for feedthroughs A, B, C, D using 850 nm signals by comparing readings before and after the neutron irradiation. Type I and Type II feedthrough test results are shown in Table 14.

TABLE 14 **Neutron Fluence Radiation Test Results**

Feedthrough Type	Avg. dB from initial recorded post-test
I	0
II	- 0.07

Overall optical performance in neutron fluence irradiation was excellent with no change noted for Type I and less than 0.1 dB decrease measured for Type II. Optical monitoring was not conducted during the exposure due to impracticality with the rotating cylinder set-up.

Complete data recordings are shown in Appendix 4. Leak rate testing was performed after the neutron fluence irradiation exposure, to 10^{-11} cc/sec helium with no detected leaks.

2.6.1.6 Gamma Radiation (Ref. para. 2.7 of LC-T-92-C027-TP; Appendix 2)

Four fiber optic feedthroughs, A, B, C, D as listed in Table 15, were gamma irradiated with flash x-ray dose exposure.

Requirement: Type I and Type II feedthroughs were to be exposed to the gamma flash x-ray dosage as described in Appendix 7 of LC-T-94-C027-TR.

Results: Change in optical transmittance was measured by comparing initial signal levels prior to test to the final signal levels at the end of the test.

Optical signal change due to influence of radiation exposure was recorded as shown in Appendix 4. The exposure dose rate levels are shown in Appendix 7, Table 2 of LC-T-94-C027-TR. Type I and Type II feedthrough test results are shown in Table 15.

TABLE 15 Gamma Radiation Test Results

Feedthrough Type	Feedthrough (channels)	Avg. dB change after dose
I	A (1)	-0.01
I	B (1)	-0.09
I	C (1)	-0.03
II	D (4)	+0.06

Overall optical performance as measured and shown in Table 15 was excellent with all changes less than 0.1 dB average in each feedthrough. The signal waveform, over a 5×10^{-6} sec time from exposure of the flash x-ray, shows very rapid recovery of the fiber from radiation influence. This can be seen in the "signal" waveform data traces in Appendix 4, Gamma Radiation data sheets. Complete optical data readings are shown in Appendix 4.

Leak rate testing was performed after the gamma irradiation exposure, to 10^{-11} cc/sec helium with no detected leaks.

2.6.1.7 Ionizing Dose (Ref. para. 2.7 of LC-T-92-C027-TP; Appendix 2)

Four fiber optic feedthroughs, A, B, C, D as listed in Table 16, were irradiated with ionizing dosage.

Requirement: Change in optical transmittance was to be recorded by comparing dBm readings during total ionizing radiation exposure with the initial dBm readings prior to exposure. The exposure time was to be approx 30 sec. at 3000 rads (Si), 72 sec. for 10,000 rads (Si), 100 sec. for 20,000 rads (Si), 300 sec. for 50,000 rads (Si) and 500 sec. for 100,000 rads Si. Details of test equipment and set up are shown in Appendix 7, Final Report LC-T-94-C027-TR.

Results: Change in optical transmittance was recorded as planned before and during exposure to ion dose radiation. Exposure dose levels, time, optical recorded readings are all found in Appendix I. Type I and Type II feedthrough test results are shown in Table 16.

TABLE 16 <u>Total Ionizing Dose Test Results</u>

Feedthrough Type	Feedthrough (channels)	Avg. dB change after dose (rads)				
		3K	10K	20K	50K	100K
I	A (1)	+0.02	+0.03	+0.05	+0.05	+0.05
I	B (1)	-0.01	-0.02	-0.02	+0.07	+0.02
I	C (1)	+0.06	+0.06	+0.27	+0.27	+0.20
II	D (4)	+0.02	0	-0.02	-0.05	-0.03

Overall performance in ionizing dose irradiation was less than 0.1 dB for all feedthroughs except the Type I unit which was constructed with gold-coated fiber. This fiber exhibited an <u>increase</u> of transmitted signal at the longer exposure times/higher dosage of 0.2 to 0.3 dB.

Complete optical data readings are shown in Appendix I. Leak rate testing was performed after the ionizing dose radiation exposure, to 10^{-11} cc/sec helium with no detected leaks.

2.6.1.8 Final Leak Rate (Pressure Differential) Levels

Hermeticity of all units was checked initially, prior to any testing for set A, B, C, D (radiation testing feedthrough units). The leak rate level of 10^{-11} cc/sec was checked again following every test. Always, the units passed this check including after the final test for each set of feedthroughs. This verifies that the hermeticity achieved in initial construction maintains integrity even after exposure to severe and varied radiation conditions.

2.6.2 Results and Accomplishments

As described in 2.6.1.8, the hermeticity of the developed, constructed and tested feedthroughs was proven to be maintained even after exposure to harsh radiation testing. The optical signals were slightly affected by tests as shown in the results of Tables 14-16. The performance of the tests was intended to simulate conditions anticipated to be encountered in space use at cold (cryogenic) and hot (in proximity of rocket engine walls) conditions and in radiation exposure while in-flight and/or while in earth storage. Radiation can be a real event in space or on earth in waiting, causing sometimes darkening of fibers and thus loss of optical signals.

2.6.3 Conclusions - Task 6

Radiation exposure did very little to affect the developed feedthrough test units in either optical performance or hermeticity. Some observations follow. Through all these tests, the gold fiber appears to be too brittle to sustain the mechanical tests. The hytrel buffer tubing used to protect the fibers was unsuitable in the range of temperatures used. Another protective tube should be used where tubing is needed. The Brand Rex cable jacket performed well through all tests. This jacket material would be suitable for tubing (perfluoroalkoxy-PFA or fluorinated ethylene propylene-FEP). The polyimide fiber appears to be most useful in terms of performance without degradation in the radiation and optical tests.

2.7 Task 7 - System Design and Specifications

2.7.1 Objectives and Approach

Fiber optic hermetic feedthroughs must provide adequate sealing at pressure differential bulkheads. The fibers must be hermetically sealed within the housing and the sealing material must maintain that pressure differential capability even under harsh environmental and mechanical conditions.

A system was designed to provide for two types of fiber optic multi-channel feedthroughs. Type I has continuous, unbroken passing through it and Type II has fibers which terminate with an optical hermetic seal in pin termini so that a standard mating connector half with socket termini could be connected and disconnected when needed. It was recognized that MIL-C-38999 Series 3 or Series 4 is a rugged connector with multichannel capability and this connector style was chosen for the developed feedthrough units. Type I feedthroughs utilize the backshell accessory coupling threads standard on MIL-C-38999 Series 3 or 4 connectors and the bulkhead mount receptacle flange style was also used as seen in Figures 5 and 21. Backshells were developed to protect and isolate from external forces the exposed fibers passing through the feedthrough hermetic sealing area. Type II feedthroughs used similar features for passing through the bulkhead with a hermetic-sealed receptacle and for backshell protection. The hermetically sealed pin termini were designed with the mating end profile of MIL-T-29504/4 fiber optic termini and thus they mate easily with standard MIL-T-29504/5 socket termini in standard MIL-C-

38999 Series 3 or Series 4 plugs.

The design objectives were accomplished and hermetic sealing was evaluated for various candidate fibers, sealing materials and methods of assembly. The overall recommended fiber is polyimide-buffered fiber sealed with polycrystalline ceramic in aluminum housings. To verify the ruggedness and integrity of the developed feedthroughs, tests were planned and conducted on prepared test units.

Description of testing performed has been presented along with results of optical signal monitoring during the environmental and mechanical test exposure. The preparation of test items is described including insertion-loss due to installation of feedthrough units. Tests which were conducted on test items have been described including pressure differential, temperature cycling (thermal shock), random and sinusoidal vibration, mechanical shock, salt spray, humidity and radiation. A description of the testing and data recorded are included in appendices. Results of optical signal monitoring before, during and after testing are presented.

2.7.2 Conclusions - Task 7

A proven, rugged reliable working system of fiber optic hermetically sealed feedthrough units has been developed, tested and documented in this Phase II SBIR development contract effort. These feedthroughs provide sealing and maintain optical signal transmission capability under harsh conditions of thermal shock, humidity, salt spray, vibration, mechanical shock and radiation.

2.8 Management and Documentation

2.8.1 Management

The contract effort has been managed as a program team activity under the principal investigator, Dr. Robert J. Fan who provided leadership through task planning, reporting, scheduling and directing of the development effort.

2.8.2 Documentation

All areas of research, information gathering, design, experimentation, reporting, planning, testing and interpretation have been documented throughout the contract effort.

The major areas of documentation are listed below with a brief description.

2.8.2.1 Monthly Reports

Throughout the contract period, monthly reports of progress, status, results and plans have been prepared and submitted to NASA. These reports are numbered from LC-T-92-C027-2 through LC-T-92-C027-24. The reports are required by contract data deliverables Section F-7B.

2.8.2.2 Interim Reports

Interim reports summarizing the activity of each six month portion of the contract progress have been prepared and submitted to NASA. These have been in the form of Interim Progress Meetings with summary report.

2.8.2.3 Briefing Reports

Briefings have been held at times during the contract effort to discuss in detail the progress and direction of the work. Briefings took place August 27, 1993 LC-T-92-C027-17 and June 1, 1992 (LC-T-92-C027-3) at NASA Lewis Research Center. A summary of contract progress was prepared for submission and presentation at the 1993

Cryogenic Engineering Conference in Albuquerque, NM held July 12-14, 1993 (LC-T-92-C027-16). A conference call was held January 27, 1993 as an extensive Contract Interim Progress Report. (Summary in LC-T-92-C027-10). A final conference call took place for April 29, 1994 to discuss the final contract findings. A presentation of a paper reviewing contract results is planned for the IICIT annual symposium in September, 1994.

2.8.2.4 Test Plan

A comprehensive test plan was prepared to outline the tests which would be conducted on the developed feedthroughs. This Plan is included in this Final Report as Appendix 2 and includes test units to be prepared and exposed to the defined environmental, mechanical and radiation tests. The Plan, LC-T-92-C027-TP is included herein as Appendix 2.

2.8.2.5 Test Report

Following completion of the entire series of tests, a comprehensive report of tests was prepared reviewing the tests conducted, data sheets, summarized results and conclusions based on findings. Excerpts from the Test Report LC-T-94-C027-TR are contained in this report in

Tasks 5 and 6 reports and in Appendix 1, 3, 4, and 5.

2.8.2.6 Final Report

The entire Phase II Contract Effort has been summarized in this Final Report, LC-T-94-C027-FR. Contract history of development, component fabrication, assembly of units, testing and conclusions have been presented as required in contract data Section F-7C.

3.0 Overall Results and Conclusions

The Phase II contract effort has resulted in the completion of construction and successful testing of feedthrough units. The following results and conclusions are summarized with backup information extensively reviewed in this Final Report.

* Type I (Figures 5, 21) feedthrough units can successfully be constructed to pass 10^{-11} cc/sec Helium leak rate test.
* Type II connector receptacle/fixed fiber (Figure 6) feedthrough units can successfully be constructed to pass 10^{-11} cc/sec Helium leak rate test.
* Feedthrough housings may be constructed of

aluminum.

* Sealing material recognized as superior is a polycrystalline ceramic melted sealant.
* Optical fibers recognized as superior are polyimide buffered glass/glass fibers.
* Type II feedthroughs can be successfully constructed with a standard interface, MIL-C-38999 Series 3 or Series 4 bulkhead-mount hermetically sealed receptacle.
* Type I and II feedthrough can be built with accessory backshells which will ruggedize and protect the units and fiber optic cables from damage in severe vibration, mechanical shock, salt spray, thermal shock, humidity and radiation exposure.
* Feedthroughs may be single channel or any number of channels with units built and evaluated up to 28 channels for hermeticity.
* Optical signal transmission is minimally affected by any of the severe mechanical, environmental and radiation exposure induced on the test feedthroughs.
* This technology may be applied to other configurations which require hermetic sealing for fiber optic signal transmission in harsh environments such as in the proximity of Space

Shuttle engines.

* Feedthroughs successfully operate in cryogenic temperatures (-200° C) and in high temperatures (+200° C).

4.0 Potential Commercial Applications

The main objective of the Phase II development and test program was to successfully produce feedthroughs which would operate without degradation in extreme cold (cryogenic) and hot environments. The test results show that this is indeed the case. Many other military, space, aerospace and commercial uses can be anticipated for this fiber optic hermetic feedthrough technology. Examples of contacts recently made give a good indication of the potential diversity of new applications.

Cited are three contracts which have been made showing significant interest in the hermetic sealing capability over a wide temperature range as developed and demonstrated in this contract effort. One contact was a visit by McDonnell Douglas helicopter personnel. They expressed interest in the use of developed feedthroughs for rugged Army and commercial helicopter applications requiring a broad range of temperature tolerance in bulkhead feedthrough locations.

Another contact was from technical personnel of NASA Lewis Research Center who need a feedthrough which will operate at elevated temperatures and also at extremely low temperatures of 4°K, nearly at absolute zero (-269° C). The LiteCom feedthrough hermetic sealing technology, tested to -200°C is likely candidate to successfully withstand this even more stringent condition of low temperature.

A third contact was from the underwater connector industry. Representatives of Ocean Projects and of Brantner Corp. visited LiteCom and are very interested in using LiteCom's developed hermetic sealing technology for use in underwater bulkhead pressure differential applications. They have asked for specific consideration of applying this technology to MIL-C- 24231 and MIL-C-24217 Deep Submergence Submarine Electrical Connectors for hybrid electrical/fiber optic applications.

Following contract completion, this technology will be made available to any application requiring this state-of-the-art extremely low hermeticity withstanding ability while withstanding stringent environmental and mechanical exposure, yet maintaining the level of optical signal transmission strength as a constant. Such exposure as the IICIT presentation should be an excellent means of getting the information out to the public on this technology.

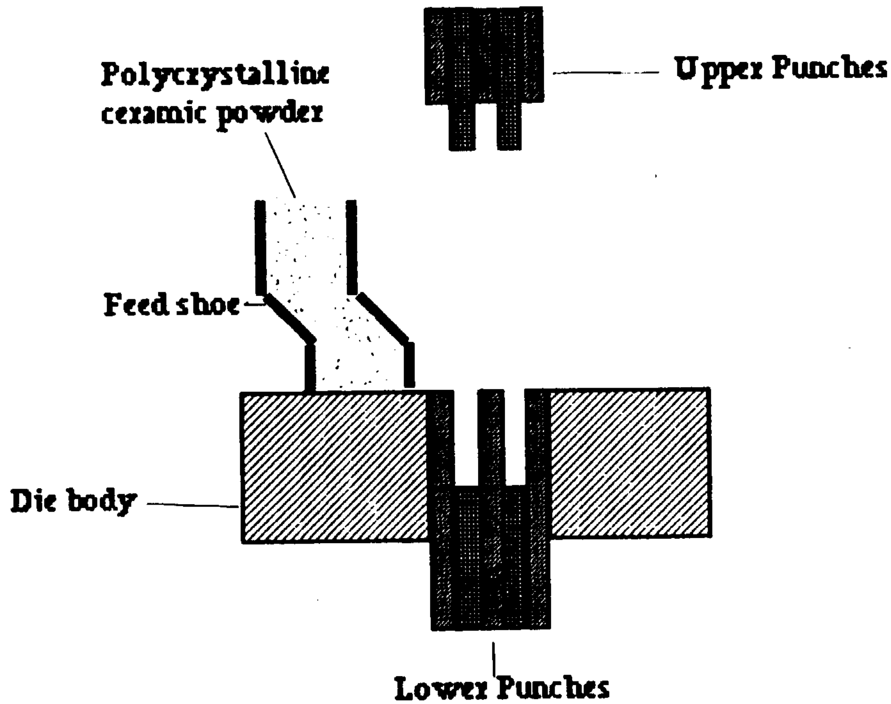


Figure 1A Preparation - Typical single-stroke mechanical press cysle

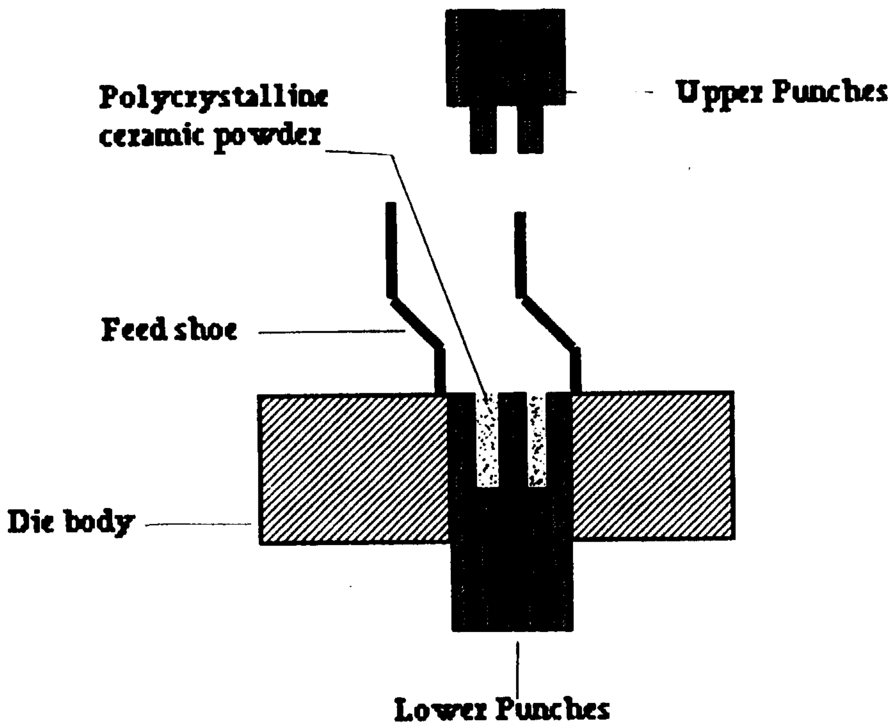


Figure 1B FILL - Typical single-stroke mechanical press cysle

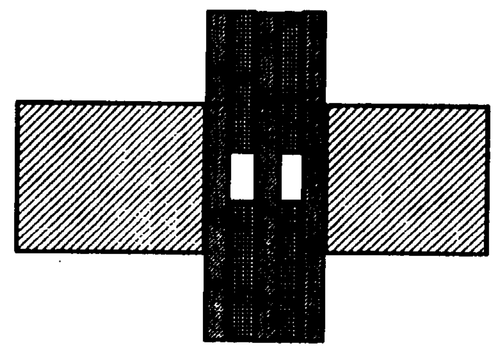


Figure 1 C - COMPRESSION
(Typical single-stroke mechanical press cysle)

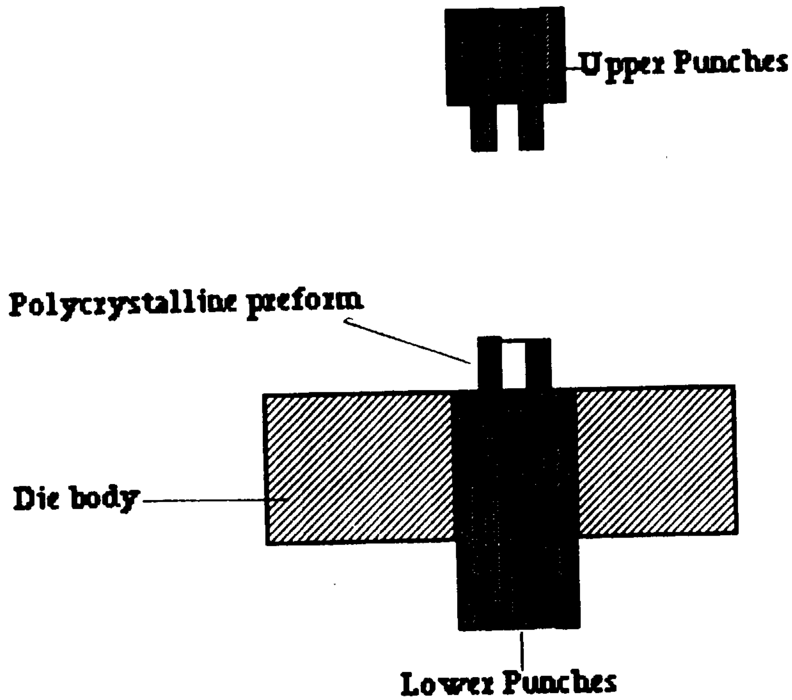


Figure 1D - EJECTION
(Typical single-stroke mechanical press cysle)

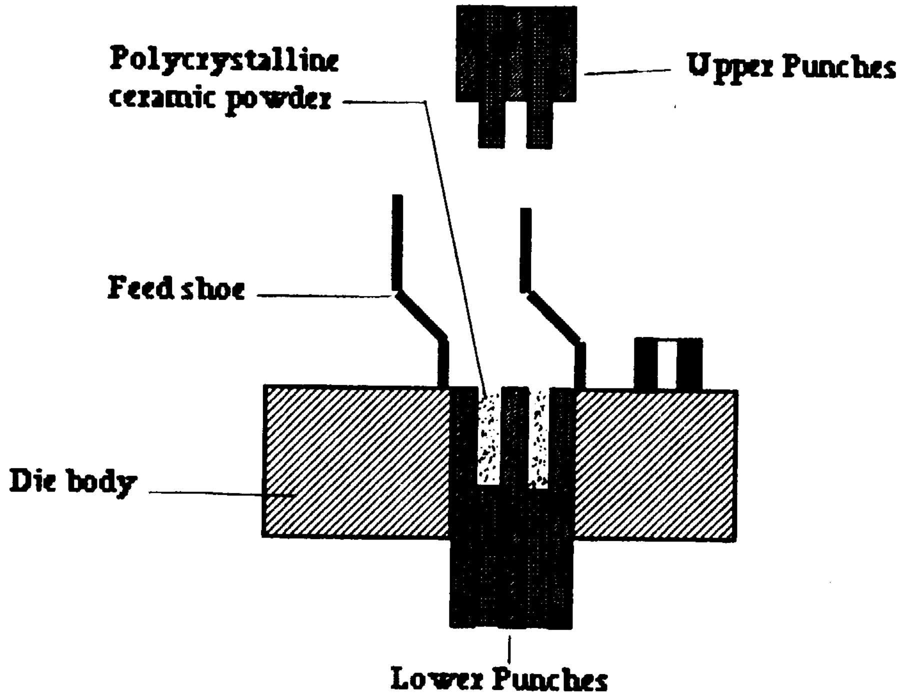


Figure 1E - RECYCLE
(Typical single-stroke mechanical press cysle)

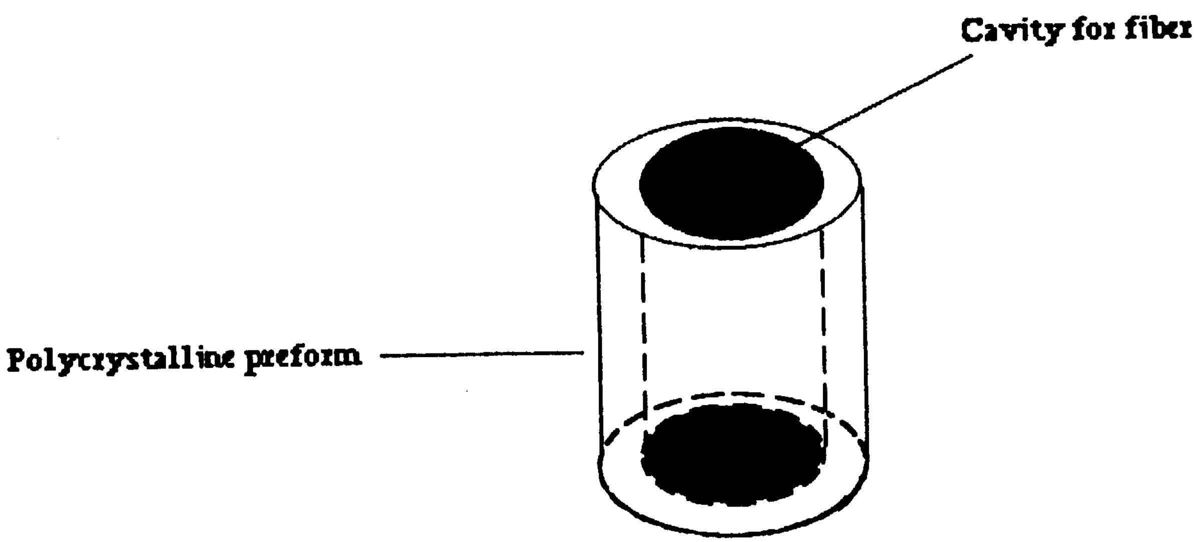


Figure 2 The pressed polycrystalline ceramic powder forms a single channel preform tubing.

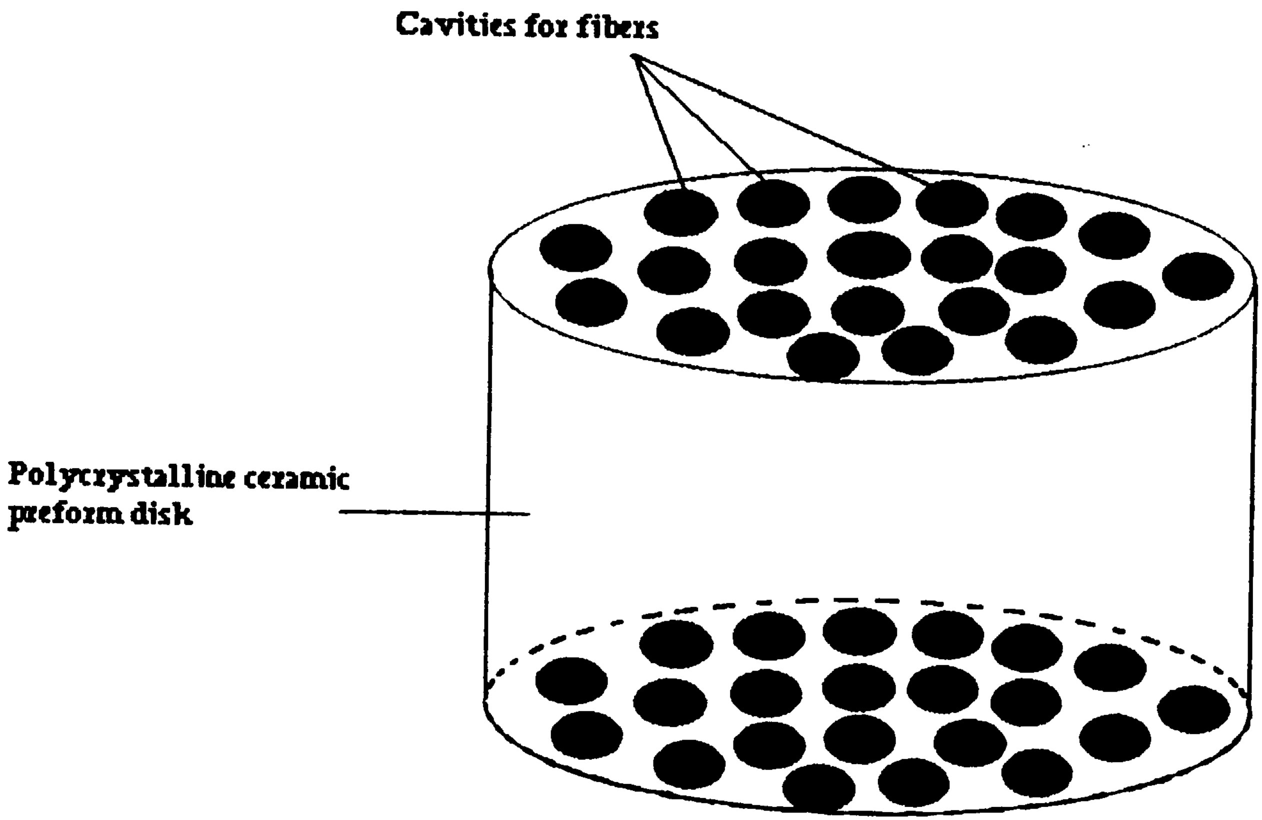


Figure 3 The pressed polycrystalline ceramic powder forms into a multi-channel preform disk

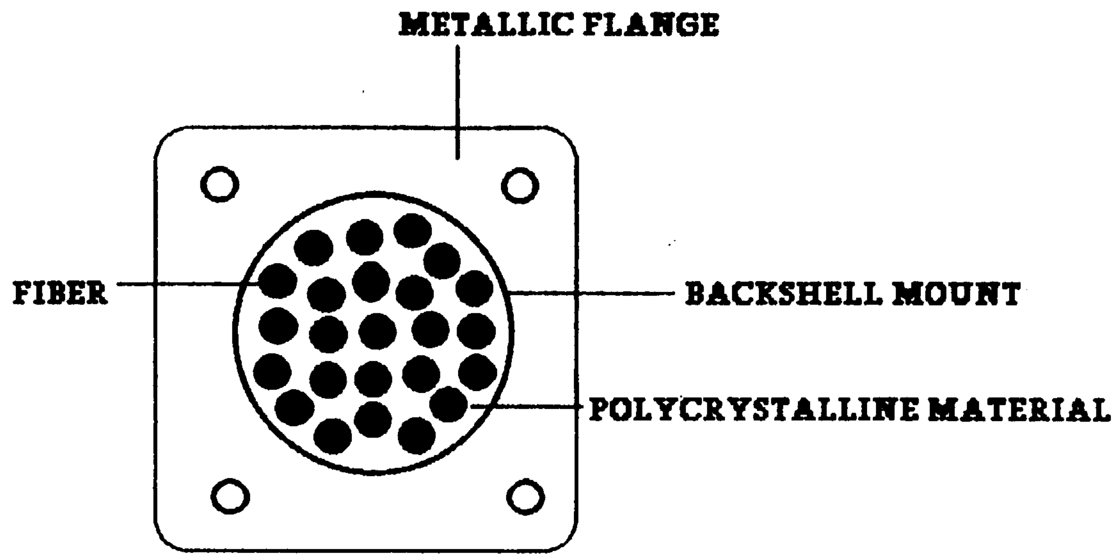


FIGURE 4 The polycrystalline preform is inserted between fibers and metallic housing prior to sintering.

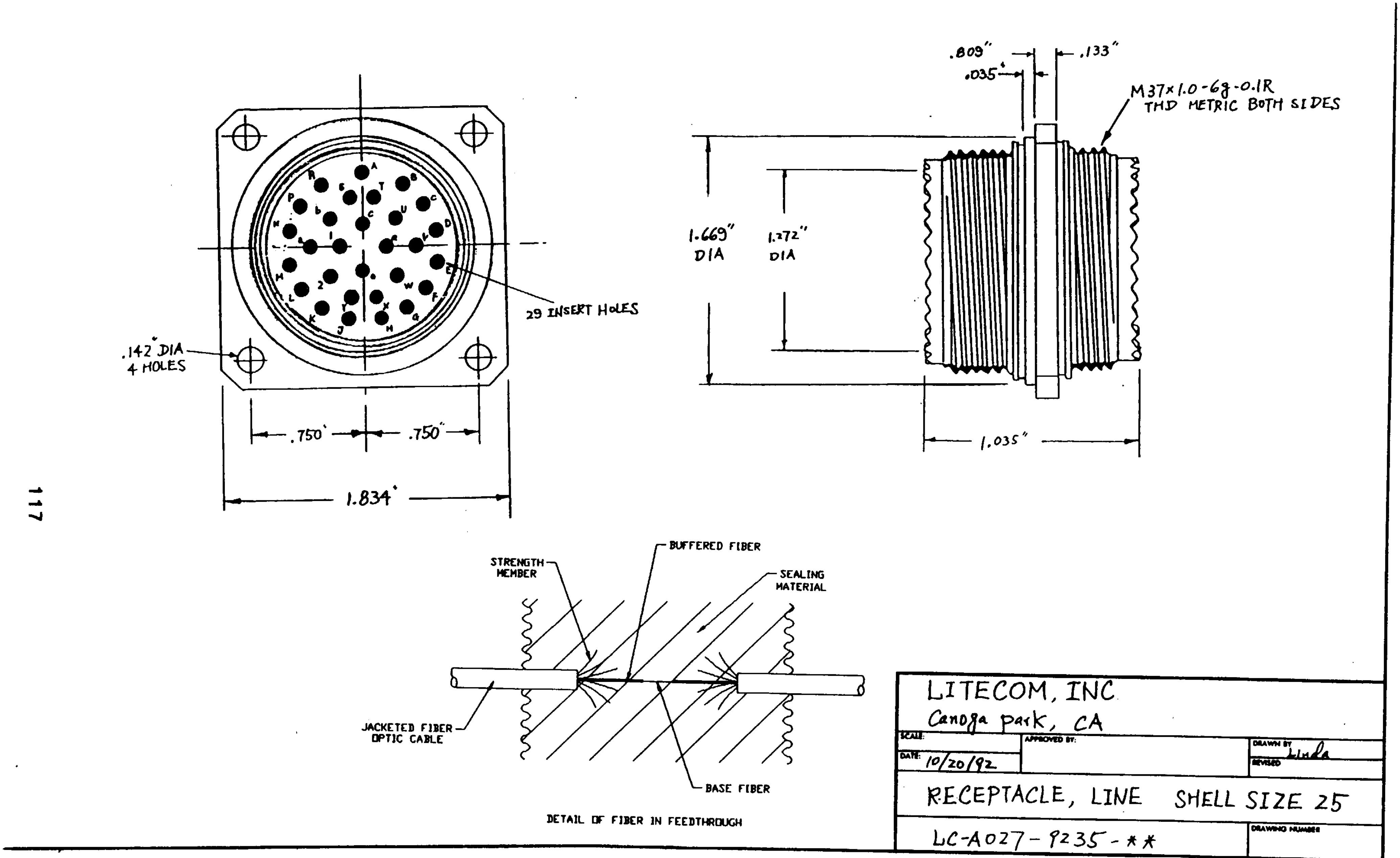


Figure 5 Type I Feedthrough

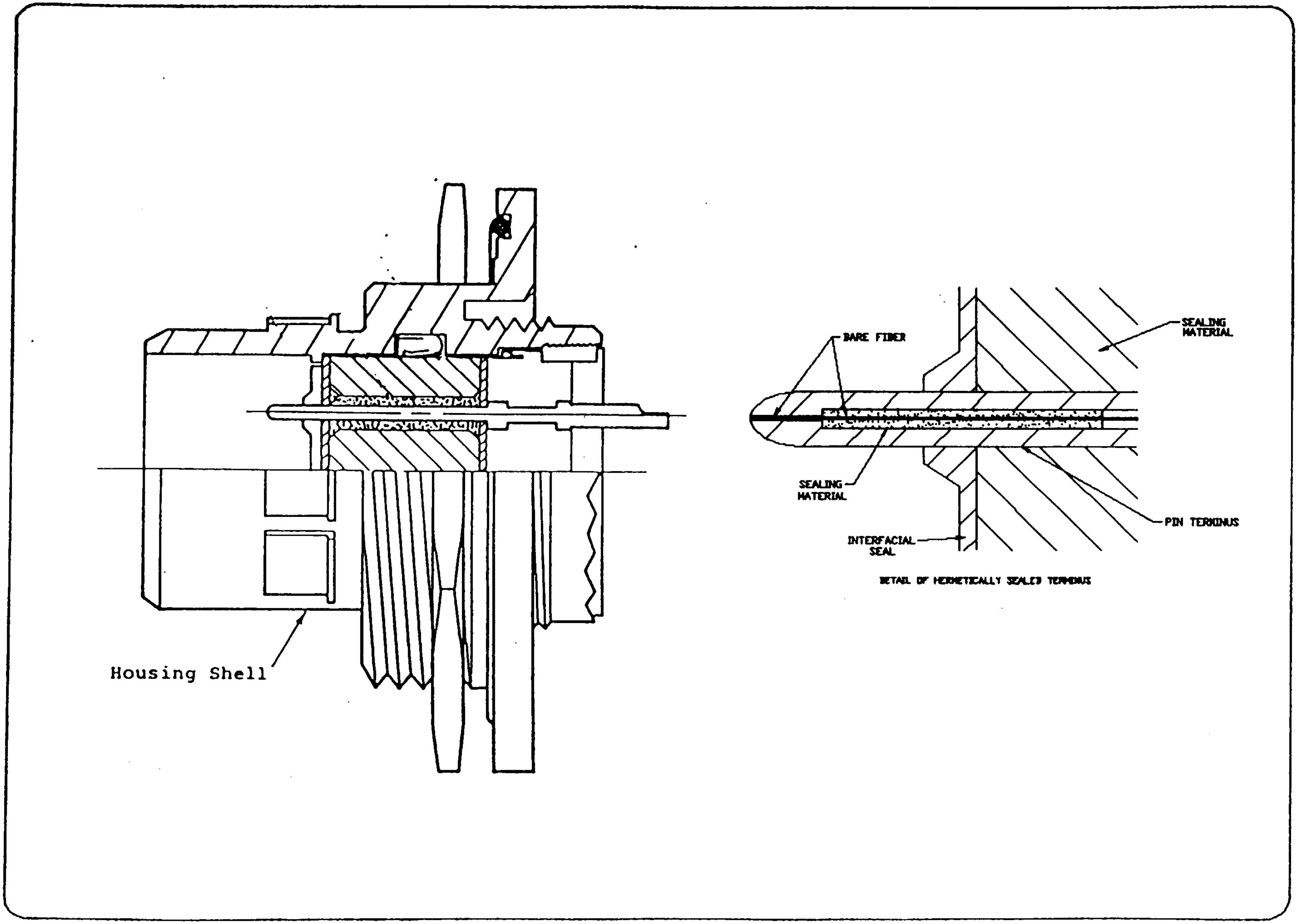
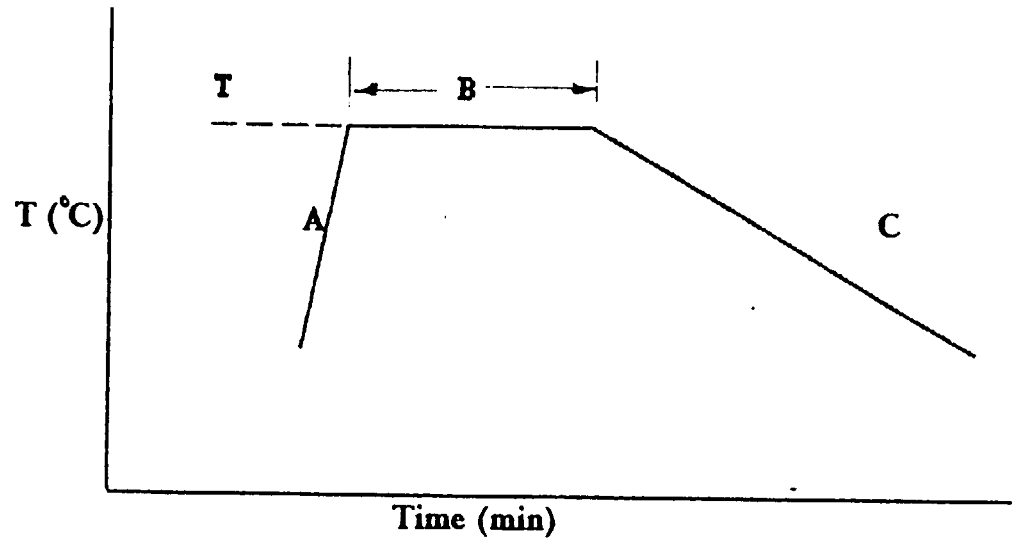


Figure 6 Type II Feedthrough



Heating rate A (°C/min)	Firing temperature T (°C)	Holding temperature B (min)	Cooling rate C (°C/min)
1	240	4	25

Figure 7 Firing Profile

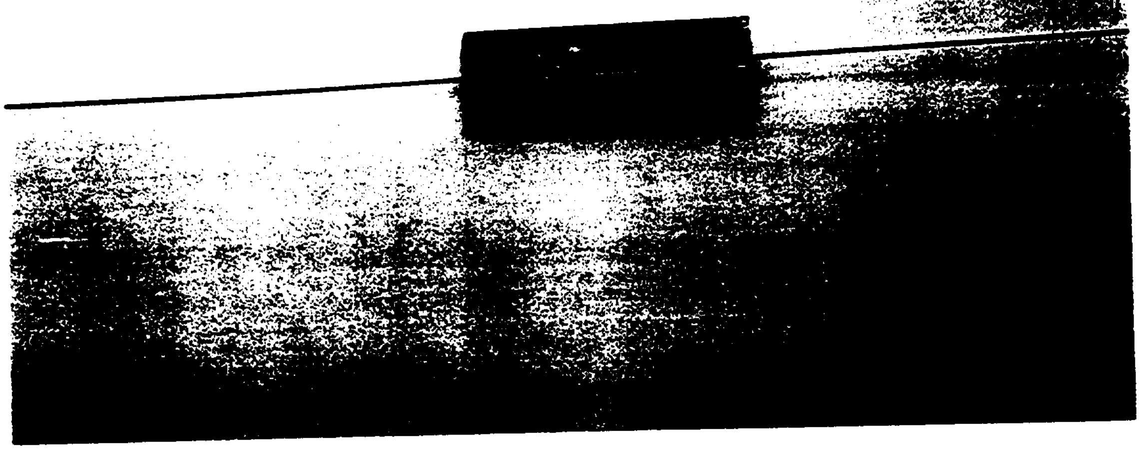
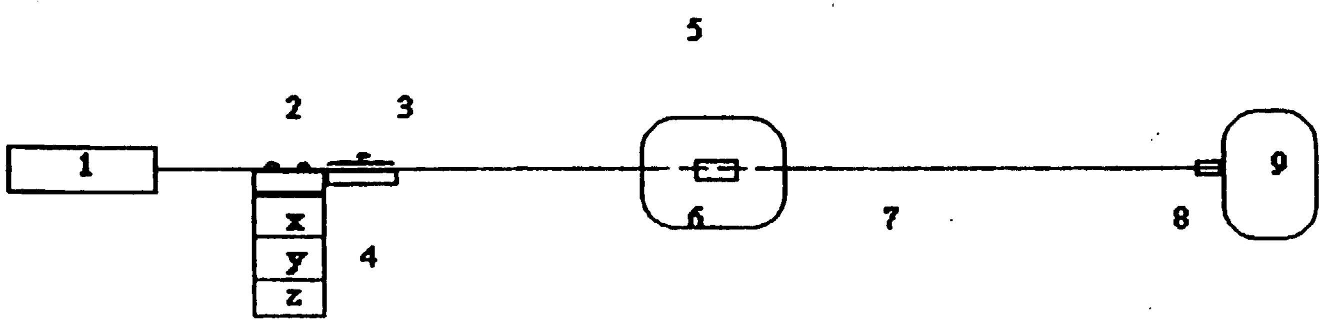


Figure 8 Photo of Polyimide Heated Fiber

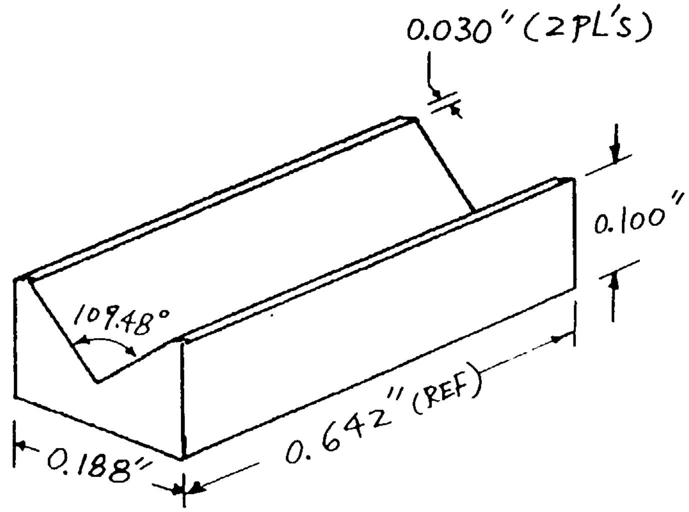
Figure 9 Photo of Gold Heated Fiber

Figure 10 Photo of Gold Heated Fiber - Detail



9. Detector, 3M Photodyne Model 2250XF
8. Adapter, ANDO type AQ-9302
7. Fiber
6. V-groove aluminum test block
5. Heater (Oven)
4. XYZ translation stages, Line Tool Co., Model A LH
3. Mode filter
2. Fiber holder
1. He-He laser, Melles Griot

Figure 11 Mockup Test Set-Up



2. **Part to be free from burrs & sharp edges**

1. **Material: Aluminum ALY 6061-0**

Figure 12 Vee Groove

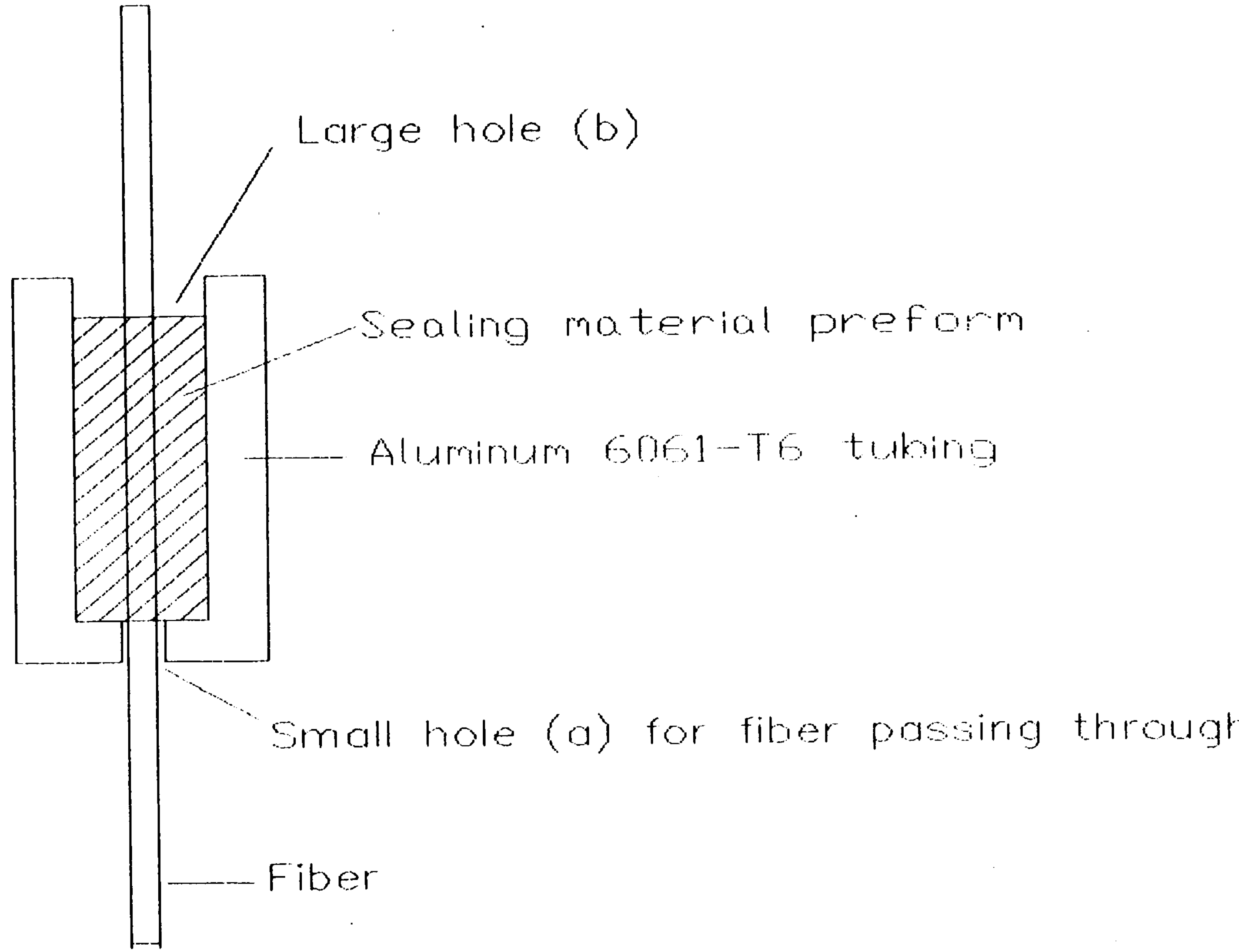
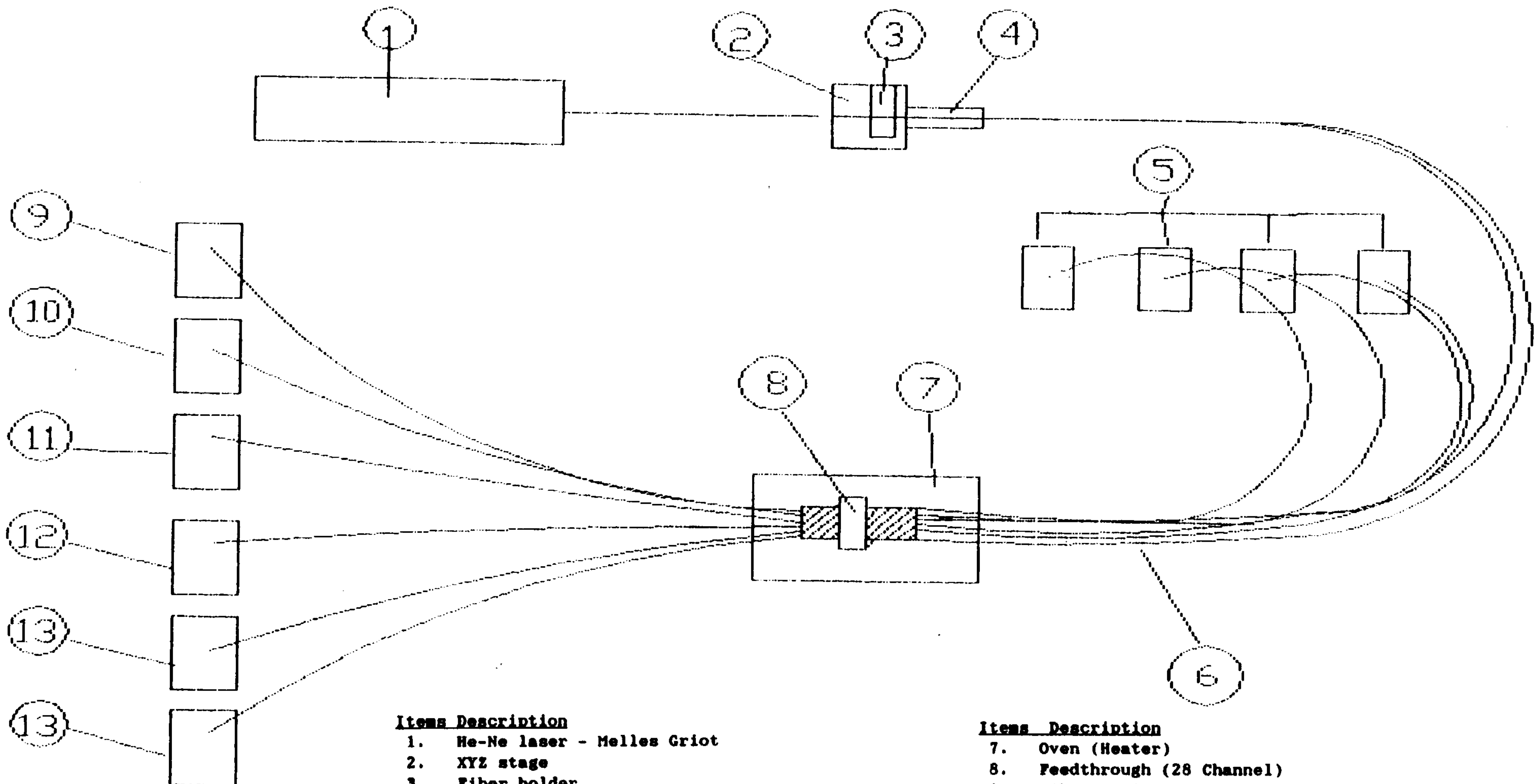


Figure 13 Single Channel Sealing Unit



<u>Items Description</u>

1. He-Ne laser - Melles Griot
2. XYZ stage
3. Fiber holder
4. Mode filter
5. 820 nm light source - S1850 Math Asso.
6. Fibers

<u>Items Description</u>

7. Oven (Heater)
8. Feedthrough (28 Channel)
9. Fiber Optic Test Set - Photodyne 2250 XF
10. Fiber Optic Multimeter - Photodyne 22XLA
11. Radiometer/Photometer - Photodyne 88XLA
12. Photodetector - Ealing 28-7870
13. Fiber Optic Power Meter - Photodyne 11XE

Figure 14 Feedthrough Test in Fabrication

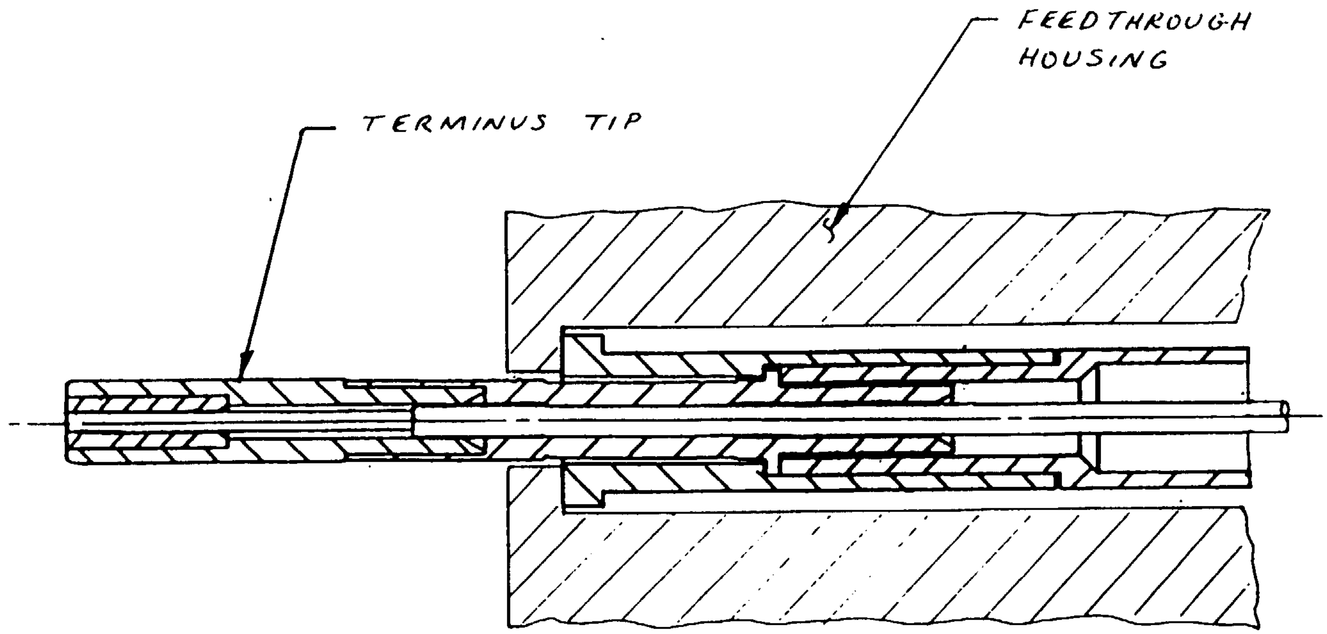


Figure 15 Terminus

A-VAC INDUSTRIES
Air-Vacuum Science and Technology

October 23, 1992

Litecom, Inc.
8033 Remmet
Canoga Park, CA 91303

C E R T I F I C A T E OF C O N F O R M A N C E

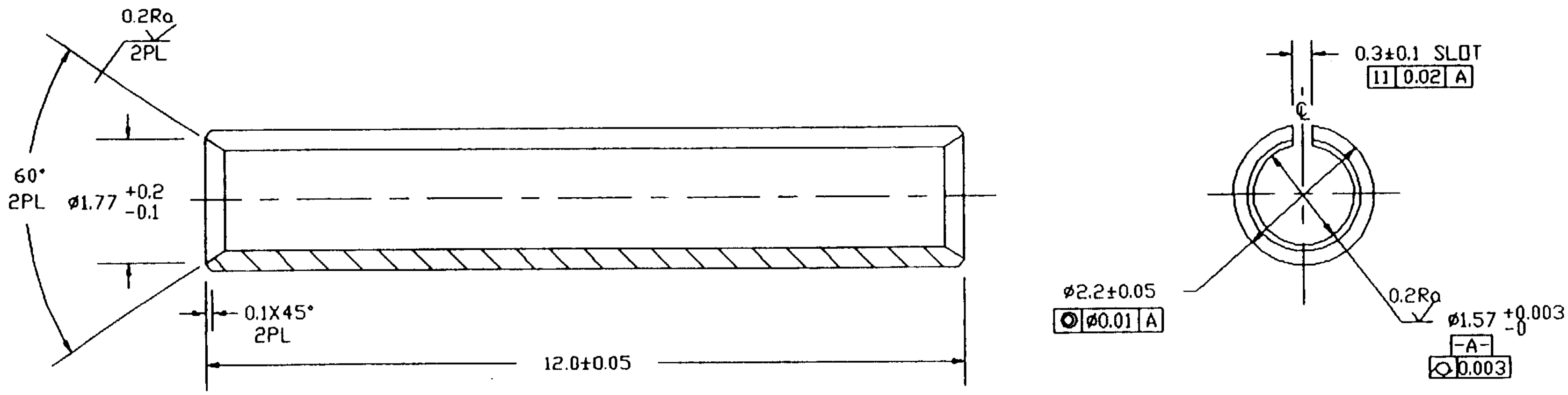
I certify that the below listed parts have been tested per accepted Vacuum Practice as specified by American Vacuum Society (A.V.S., as per standards 2.1 and 2.2), and recommended by the National Institute of Standards and Technology.

Quantity and Type of Parts:	lea Fiber Optic Feedthrough Model #C-Multi 28 S/N #200-1001-72-28
Quantity Failed: 0	Quantity Passed: lea
Date of Helium Leak Test:	10/23/92
Helium Leak Standard Used:	Model #SC-4 S/N #14699 6.75×10^{-8} cc/sec He at 72°F
Mass Spectrometer Used:	Veeco Helium Leak Detector Model #MS90AB S/N#1027 3.0×10^{-10} cc/sec He
Rate of Leak Test	3.0×10^{-10} cc/sec He

Test Performed By:______________________________
Thanh (Billy) Ly, Vacuum Technician

Figure 16 Test Results - Type I Multi-Channel Feedthrough

1845 So. Lewis Street, Anaheim, CA 92805
(714) 938-1300 • (800) 747-2821 • (619) 239-AVAC • FAX (714) 938-0899



3. PULL OUT FORCE 100-300 gr.
2. ALL DIMENSIONS ARE IN MILLIMETERS.
1. INTERPRET PER DOD-STD-1000.

QTY	FIND#	PART/IDENTIFYING	NOMENCLATURE	MATERIAL	SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES DECIMAL TOL .XX ±.03 .XXX ±.010 ANGULAR TOL ± 0°30' MEET DIMENSIONS BEFORE PLATING SURFACE ROUGHNESS NO BURRS AND SHARP EDGES CORNERS & FILLET RADII IDENTIFY PER LITECOM SPEC	CONTRACTOR NO. DAAJ02-92-C-0047 CAGE NO. DATE 9-4-93 CHECK PROJ ENG	LITECOM, INC CANOGA PARK CA. TITLE SPLIT SLEEVE, SIZE 16 DWG NO. LC-B099-9341
LC-B037-9397 / FINISH	APPR	SCALE WEIGHT SHEET
NEXT ASSY / HEAT TREAT	DRAWN C. PINEDA	

Figure 17 Split Sleeve

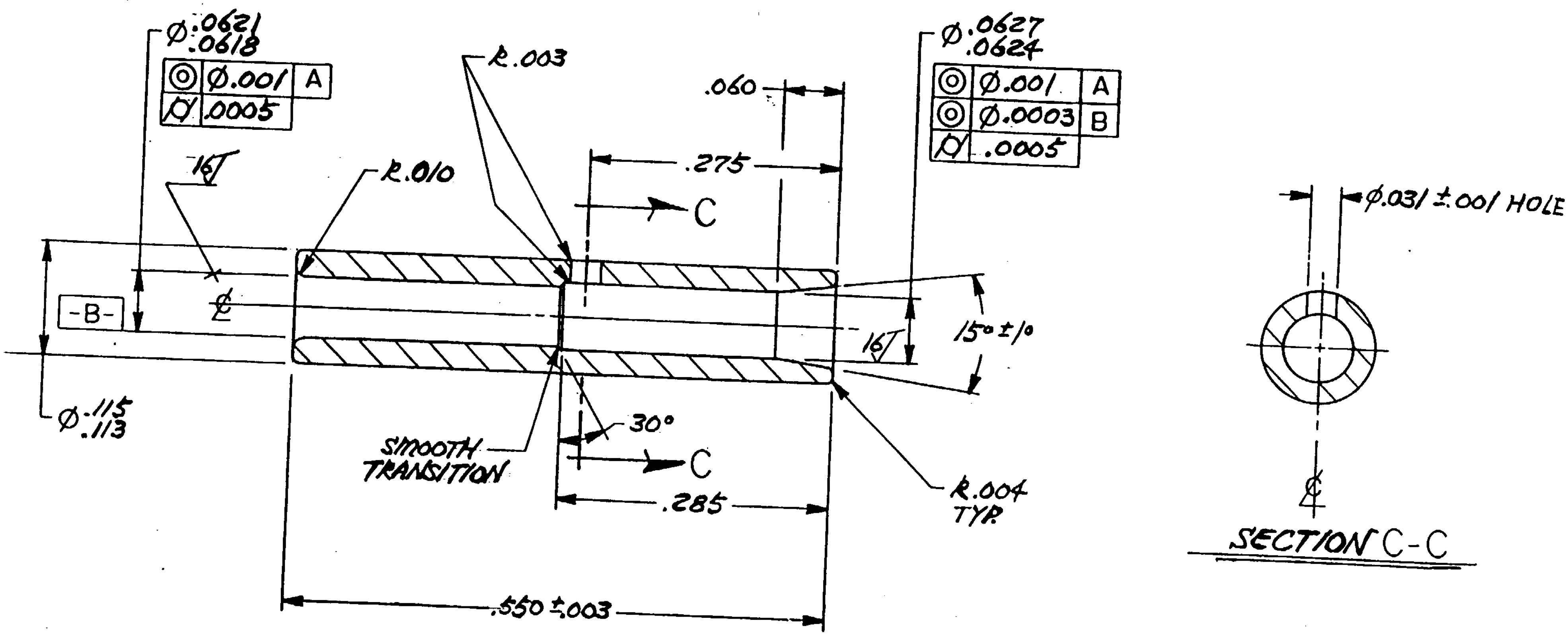


Figure 18 Alternative Version Split Sleeve

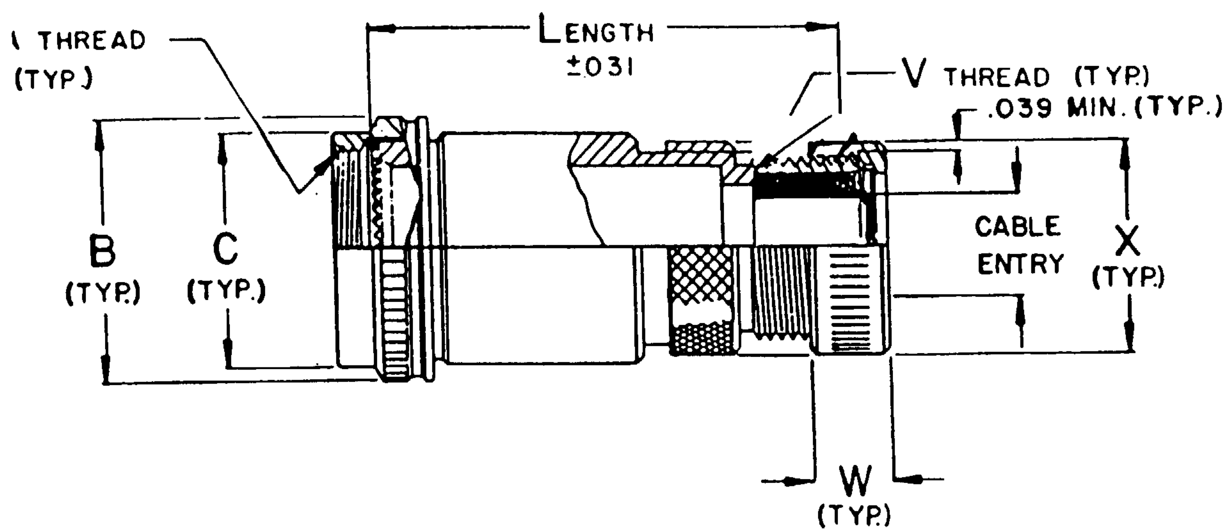


Figure 19 Straight Backshell

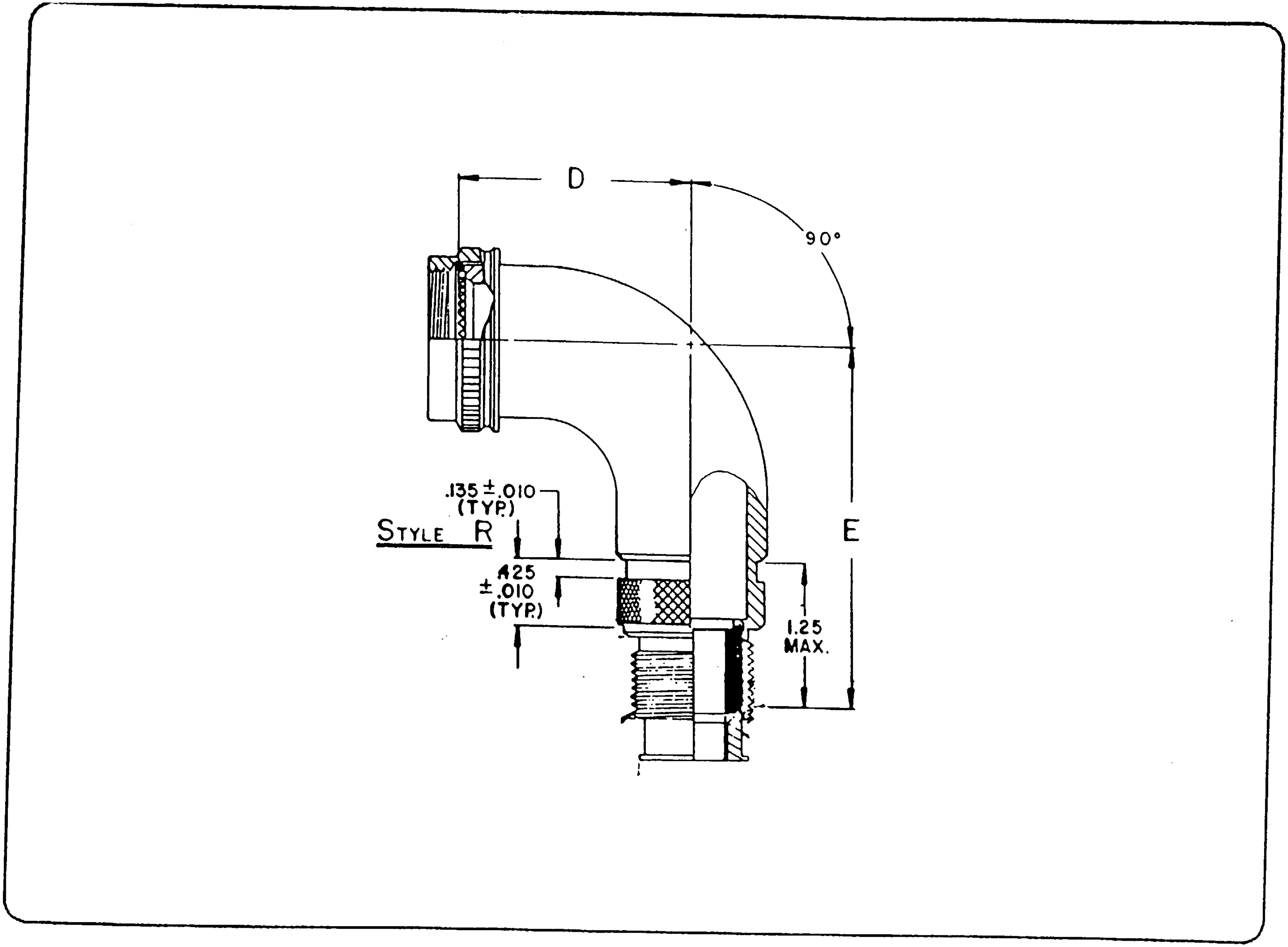


Figure 20 Right-Angle Backshell

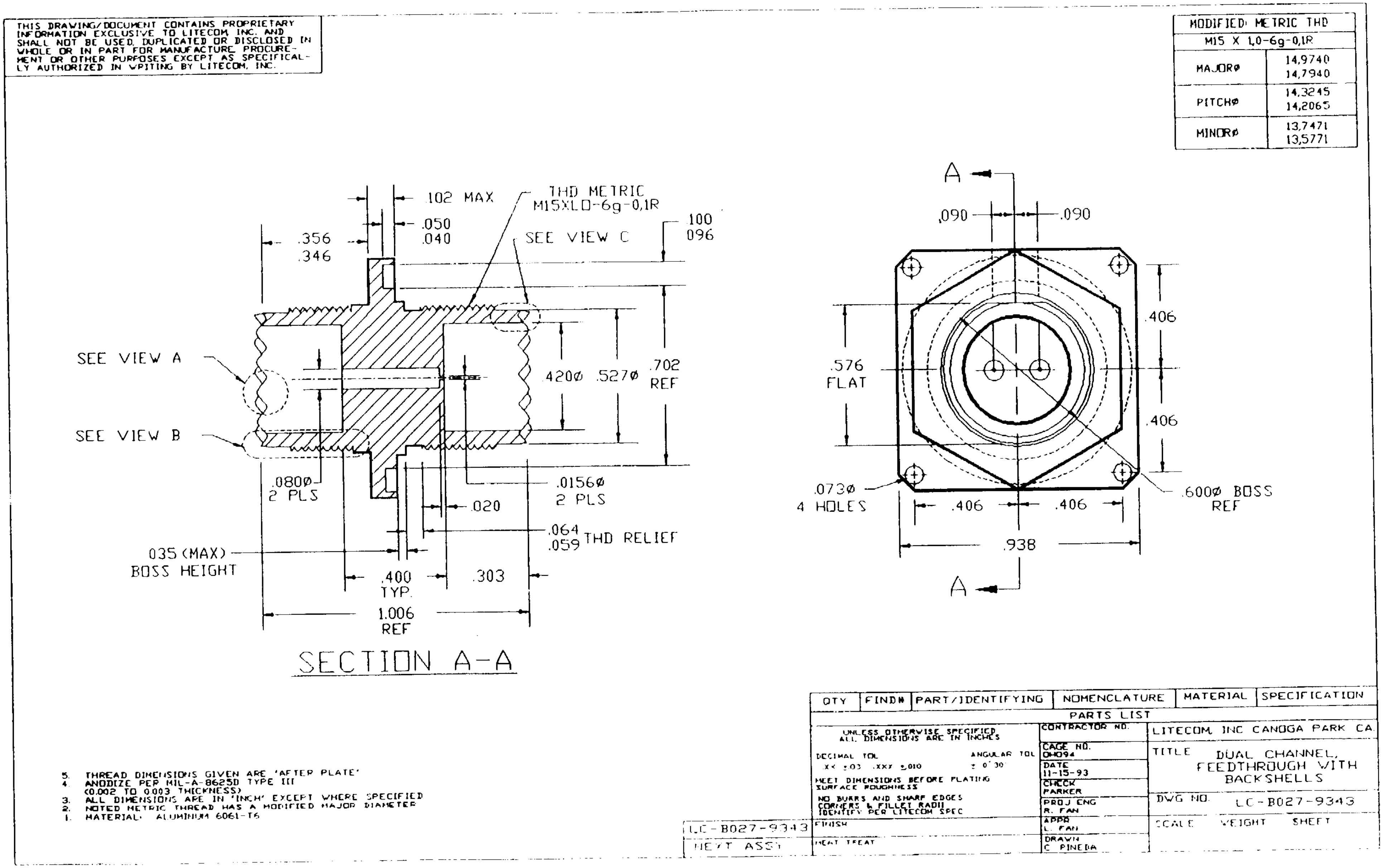


Figure 21 Type I, 2-Channel Feedthrough, Low Profile

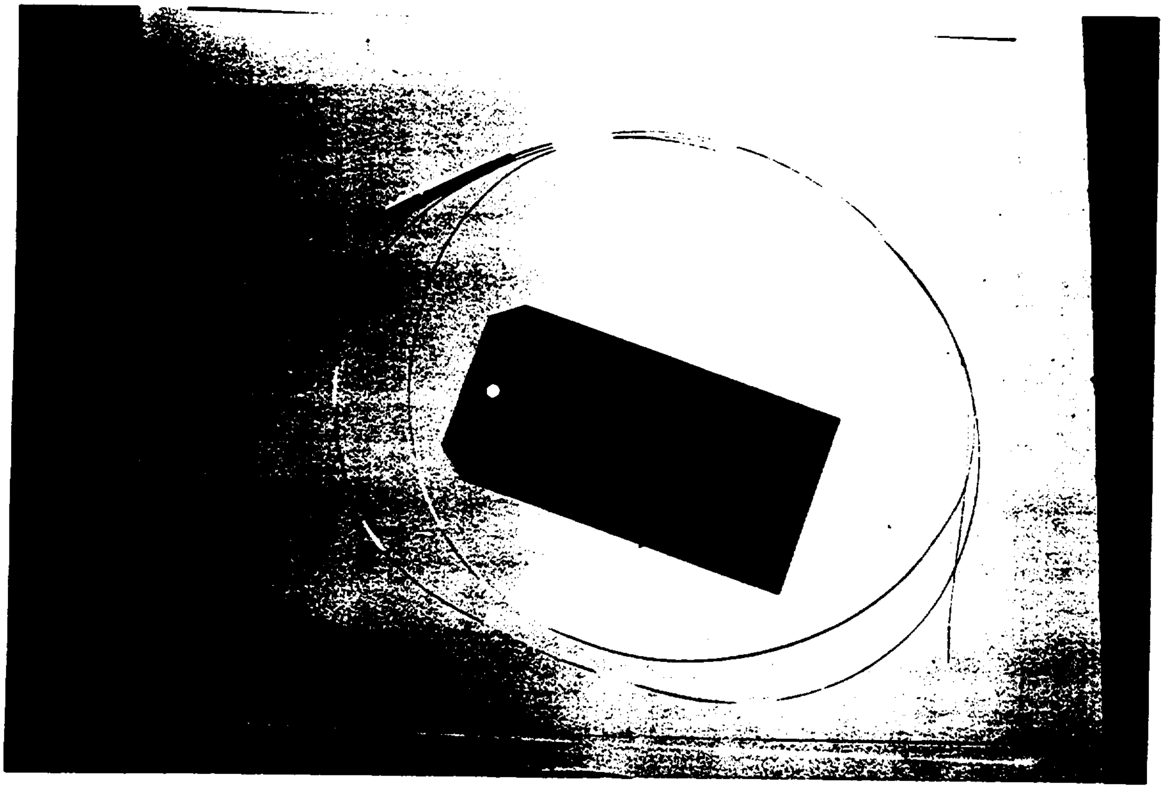


Figure 22 Gold-Coated Fiber-to-Terminus

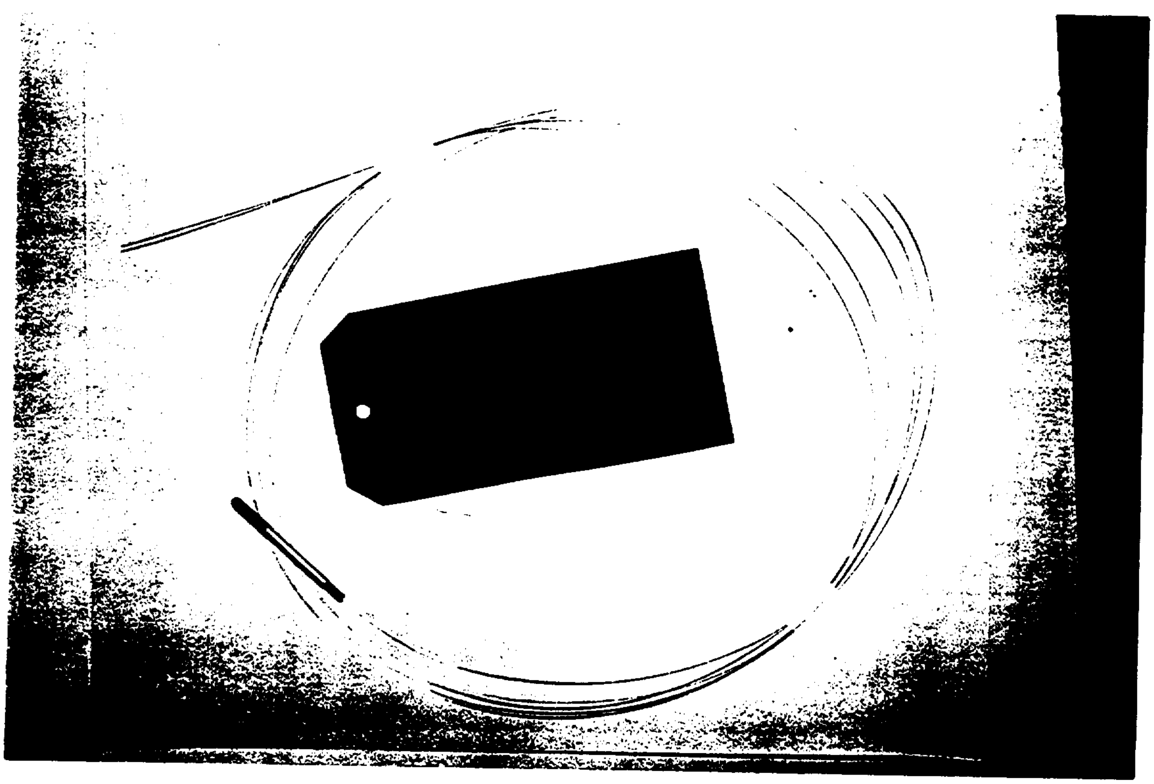


Figure 23 Aluminum-Coated Fiber-to-Terminus

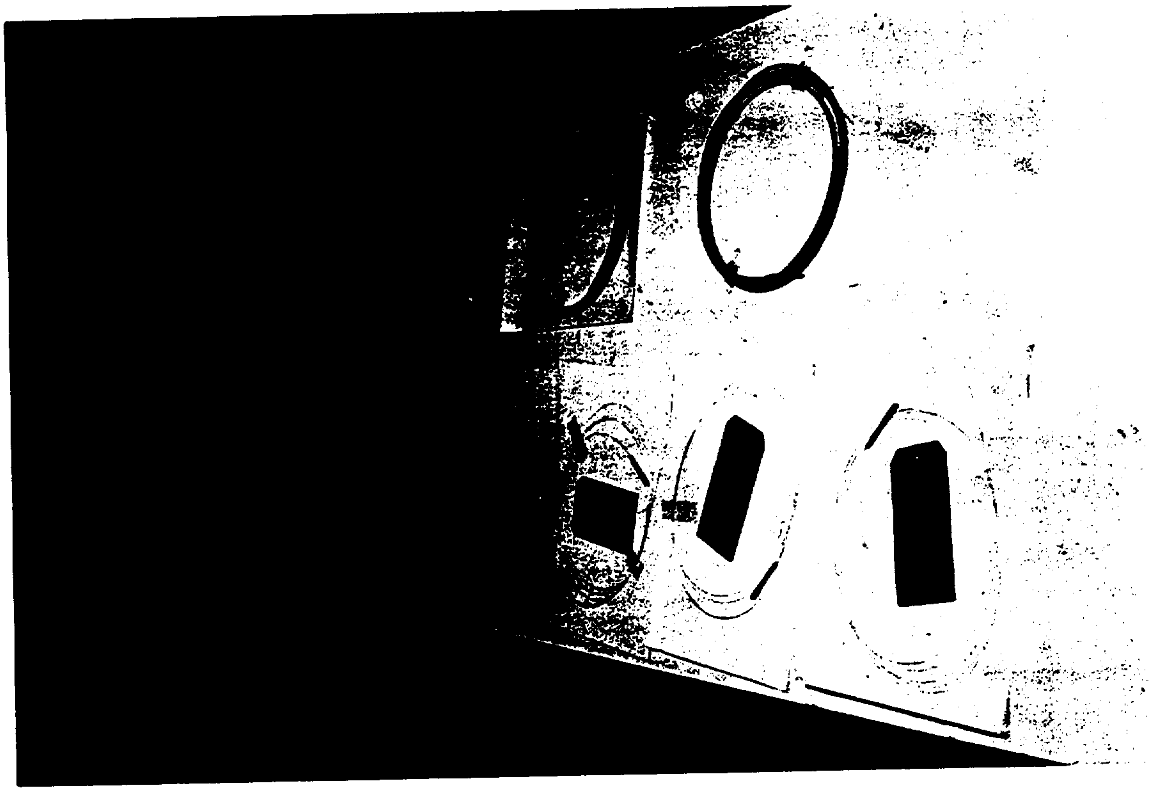


Figure 24 Polyimide-Coated Fiber-to-Terminus

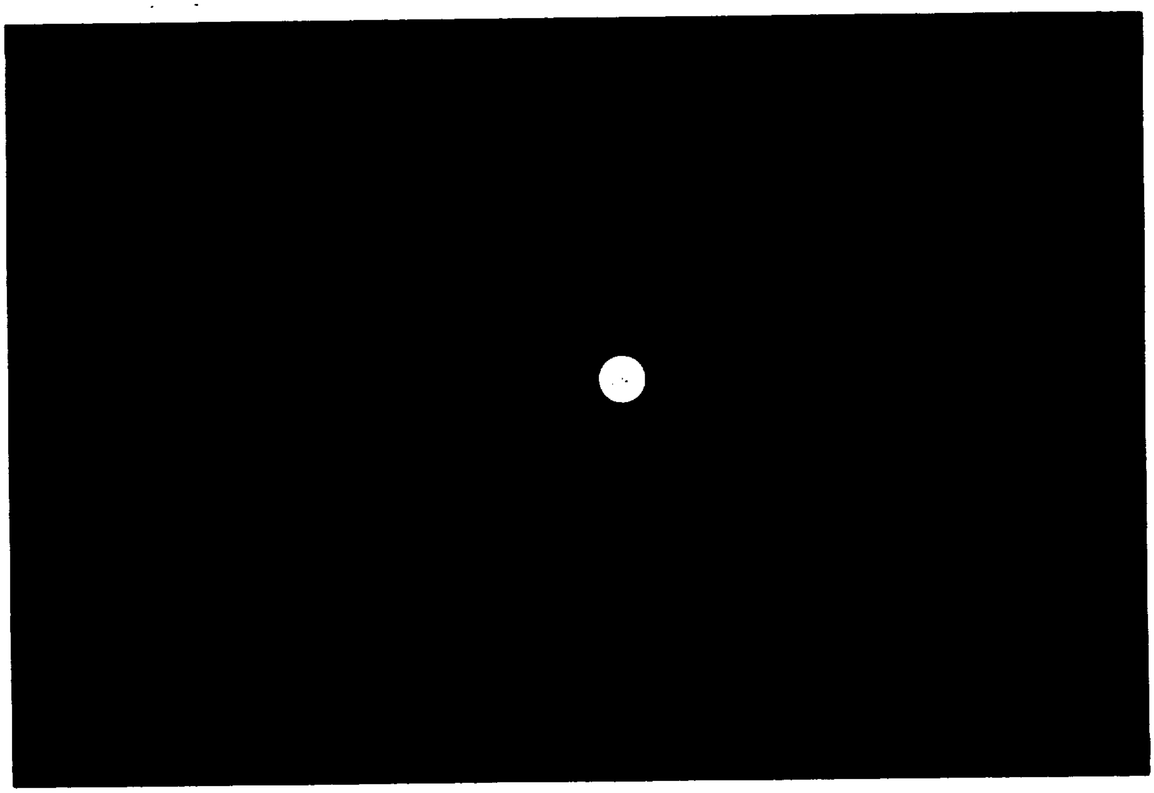


Figure 25 Polished Fiber Terminus, 100X Magnification

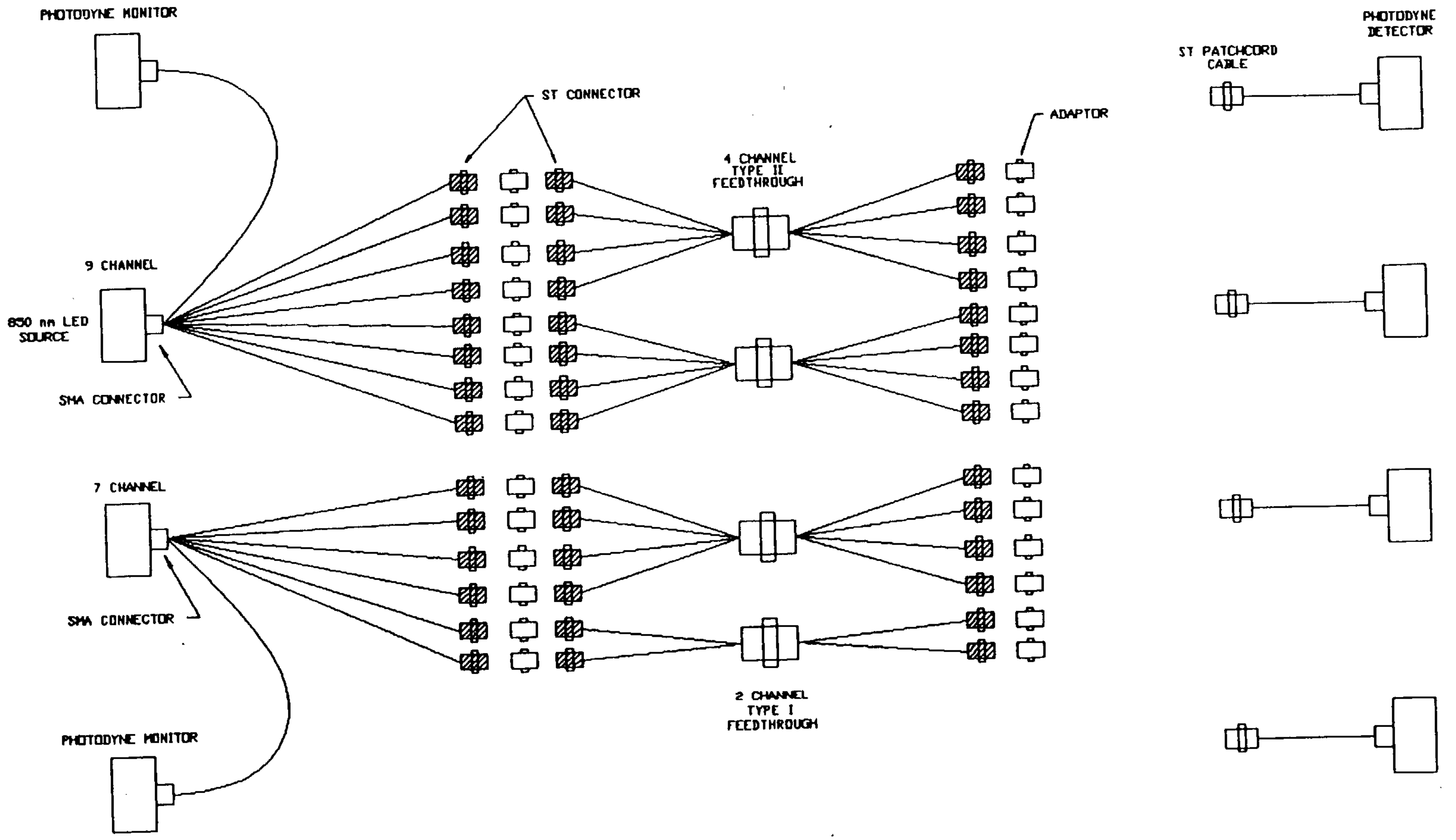


Figure 26 Optical Test Set-Up

APPENDIX 1

Final Test Report/Data

TABLE 1 Feedthrough Test Units

Ident. No.	Feedthrough Type	No. of Channels	No. of Channels Used
C1	II	4	4
C2	II	4	4
C3	II	4	4
C4	I	2	2
A	I	2	1
B	I	2	1
C	II	4	2
D	II	4	4

TABLE 2 Salt Spray Test Results

Feedthrough Type	Avg. dB from initial	
	Mid-way	Final
I	+.04	+.02
II	0	0

TABLE 3 Random Vibration Results

Axis	Feedthrough Type	Avg. dB from initial	
		During Test	Post Test
x	I	0	-.01
y	I	0	0
z	I	0	-.01
x	II	-.01	-.02
y	II	+.01	0
z	II	-.01	0

TABLE 4 **Sinusoidal Vibration Results**

Axis	Feedthrough Type	Avg. dB from initial	
		During Test	Post Test
x	I	-.01	0
y	I	0	0
z	I	0	0
x	II	0	0
y	II	-.04	-.03
z	II	+.02	+.03

TABLE 5 **Mechanical Shock Results**

Feedthrough Type	Avg. dB from initial
I	-.03
II	-.02

TABLE 6 **Thermal Shock Results**

Cycle No.	Cold Temp. (-320°F) From Initial (dB) Avg.		Hot Temp. (+392°F) From Initial (dB) Avg.	
	Type I (C4)	Type II (C1, C2, C3)	Type I (C4)	Type II (C1, C2, C3)
1	+.01	+.02	+.03	+.05
2	-.02	0	0	+.03
3	+.01	+.03	+.02	+.07
4	+.01	+.03	+.02	+.07
5	+.01	+.04	+.02	+.07

TABLE 7 **Humidity Test Results**

Feedthrough Type	Avg. dB from initial	
	Mid-way	Final
I	0	0
II	0	0

TABLE 8 **Neutron Fluence Radiation Test Results**

Feedthrough Type	Avg. dB from initial recorded post-test
I	0
II	- 0.07

TABLE 9 **Gamma Radiation Test Results**

Feedthrough Type	Feedthrough (channels)	Avg. dB change after dose
I	A (1)	-0.01
I	B (1)	-0.09
I	C (1)	-0.03
II	D (4)	+0.06

TABLE 10 **Total Ionizing Dose Test Results**

Feedthrough Type	Feedthrough (channels)	Avg. dB change after dose (rads)				
		3K	10K	20K	50K	100K
I	A (1)	+0.02	+0.03	+0.05	+0.05	+0.05
I	B (1)	-0.01	-0.02	-0.02	+0.07	+0.02
I	C (1)	+0.06	+0.06	+0.27	+0.27	+0.20
II	D (4)	+0.02	0	-0.02	-0.05	-0.03

APPENDIX 2

Test Plan

Contract NAS3-26611

Fiber Optic Cable Feedthrough and Sealing

Test Plan

Robert J. Fan
LiteCom, Inc.
20249 Elkwood Street
Canoga Park, CA 91306-2313

9 June 1993

Prepared for:

Mrs. Amy Jankovsky
Project Manager
National Aeronautics and space Administration
Lewis Research Center
Cleveland, OH 44135

TABLE OF CONTENTS

LIST OF FIGURES

1.0 Scope

The SBIR Fiber Optic data system development Phase II effort is being conducted with a research and development emphasis. The first phase included preliminary testing and the second phase includes comprehensive testing of designed, fabricated and assembled hermetic sealing feedthrough units for use in sensor systems. Because of the nature of the diverse environmental conditions which will be encountered in sensor systems use around the Space Shuttle main engine, the components must withstand pressure/vacuum and adverse environmental conditions. Components/assemblies are designed to provide improved fiber optic hermetic feedthrough units of single channel and multi-channel designs.

Testing will provide assurance that the developed feedthroughs will continue to perform the task of optical signal transmission even when subjected to adverse environmental and mechanical conditions. The test plan is designed to assure ability to continue to operate successfully by applying adverse conditions and monitoring optical performance during the tests. The adverse conditions have been chosen to simulate the anticipated environment of the Space Shuttle Main Engine and the environment of cryogenic liquid propulsion systems in the Space Shuttle as a baseline. This will apply then, to many other space environment applications.

Tests will be conducted in the LiteCom optical laboratory and in outside certified testing facilities as necessary. First, a functional check of the test items will take place, (insertion loss testing) on feedthrough with hermetically sealed fiber optic termini and signal initial level readings in straight hermetically sealed feedthrough units. Leak rate testing will be performed on all feedthrough units. Next, change in optical transmittance will be monitored concurrently with testing in temperature cycling, vibration, shock, and radiation exposure. Final leak rate testing will be conducted on feedthrough units.

2.0 Test Plan

2.1 Test Specimens

Feedthrough development in this Phase II effort includes "Type 1" continuous fiber hermetically sealed single and multiple channel hermetic fiber optic feedthroughs. "Type 2" multi-channel hermetic fiber optic feedthroughs are being developed with pin termini on one side, and continuous fibers pigtailed to the termini on the other (rear) side of the feedthrough. Test specimens of each of these two feedthrough types will be tested, multi-channel Type 1 and multi-channel Type 2.

2.2 Optical Testing

Insertion Loss testing will be conducted during construction of "Type 2" feedthrough. The Type 1 feedthrough is shown in Figure 1 with continuous fibers. A multi-channel feedthrough is shown. Figure 2 shows the Type 2 feedthrough with fibers coming into the feedthrough on one side and pin termini in a connector receptacle interface on the other side of the hermetically sealed, bulkhead mounted unit. Insertion loss measurements will be made with the fibers first continuous, then cut to terminate the hermetic pin termini on one side and terminating the mating socket termini on the other side. Final readings will be made through mated pairs of fiber optic termini and compared with the initial readings through the continuous fibers. Insertion loss testing will be conducted in accordance with EIA 455-34 (Appendix 3 of LC-T-94-C027-RF). Optical signals will be at 850 nanometer.

2.3 Environmental: pressure differential levels

Testing will be conducted to evaluate pressure differentials applicable to Space environment use of the developed hermetically sealed fiber optic feedthroughs. Following construction of multi-channel hermetic feedthroughs (Type 1) and multi-channel hermetic receptacle feedthroughs (Type 2), initial pressure differential testing will be conducted. The test procedure is shown in Appendix 5 of LC-T-94-C027-RF with detailed steps for pulling down a vacuum condition on one side of the bulkhead pressure specimen under test, and sending any leakage of helium. The leak rate, if detectable, is measured in cc/sec of helium. Leak rate of as low as 10^{-11} cc/sec have not been detected with prototype feedthroughs of this type in the Phase I effort, and these levels will be tested in this effort, approaching them incrementally. Included in Appendix 5 of LC-T-94-C027-RF is ASTM E 479-73, 'Standard Guide for Preparation of a Leak Testing Specifications". Also included in Appendix 5 of LC-T-94-C027-RF is American Vacuum Standard AVS 2.1 "Calibration of Leak Detectors of the Mall Spectrometer Type," and AVS 2.2 "Method for Vacuum Leak Calibration". The blank data sheet in Appendix 5 of LC-T-94-C027-RF should be filled out for each test conducted.

2.4 Environmental: temperature cycling (thermal shock)

Feedthrough test units will be subjected to thermal cycling. The test units will be subjected to the low temperature of -250 °F (-157 °C) for 30 minutes with a transition time of 5 minutes maximum for moving to the high temperature chamber. Soak time at high temperature of +396 °F (+200 °C) is 30 minutes. This constitutes one complete cycle. Five complete cycles will be conducted on each specimen. The test will be conducted in accordance with EIA 455-3 (See Appendix 3 of LC-T-94-C027-RF). Change in optical transmittance will be monitored before, during and after the test to indicate optical performance influence by the exposure to the varied thermal conditions. This will be done in accordance with EIA 455-20 "Measurement of Change in Optical Transmittance." (See Appendix 3 of LC-T-94-C027-RF). Optical signalling will be at 850 nanometer.

2.5 Mechanical: Vibration

Vibration testing will be conducted on the developed feedthrough test units. Both Type 1 and Type 2 feedthroughs will be tested in random and sinusoidal vibration. The testing will be conducted in accordance with EIA-455-11 "Vibration Test Procedure for Fiber Optic Connecting Devices" (see Appendix 3 of LC-T-94-C027-RF).

2.5.1 Random Vibration

Test units shall withstand, without damage of any kind, the application of a random vibration spectrum of +6 Db per octave from 20 Hz to 100 Hz and 1.0 g^2/Hz from 100 Hz to 2000 Hz in each of 3 mutually perpendicular axes for not less than 7 minutes per axis.

Change in optical transmittance will be monitored by recording 850 nm signal level before, during and after the random vibration test.

2.5.2 Sinusoidal Vibration

Test units shall withstand, without damage of any kind, the application of sinusoidal vibration, simple harmonic motion in 3 mutually perpendicular axes at a sweep rate of 1 minute per octave from 10 Hz to 2000 Hz to 10 Hz as follows:

a. 10 Hz to 55 Hz at 0.325 inch double amplitude displacement.

b. 55 Hz to 2000 Hz at 50 g's peak.

c. The sweep shall be performed three times in each of three mutually perpendicular directions.

Change in optical transmittance will be monitored by recording 850 nm signal level before, during and after the sinusoidal vibration test.

2.6 Mechanical: shock

Test units shall withstand, without damage of any kind, 3 shocks (40 G's, 11$\pm$1 millisecond half sine) in each direction of 3 mutually perpendicular axes.

The forces shall be produced by securing the connectors to a sufficient mass and accelerating or decelerating the assembly so that the specified force is obtained. Three shock pulses shall be applied in each direction of each of the three major axes. The cable shall be clamped to points that move with the feedthrough. A minimum of 8 inches of cable shall be unsupported behind the rear of each feedthrough.

The testing will be conducted in accordance with EIA-455-14 "Fiber Optic Shock Test" (see Appendix 3 of LC-T-94-C027-RF). Change in optical transmittance will be monitored by recording 850 nm signal level before, during and after the shock test.

2.7 Environmental: radiation hardening test

The developed feedthrough test units will be evaluated for resistance in radiation environments. It is important to determine what signal losses may occur as a result of the exposure to radiation. Three areas of radiation testing will be conducted. Neutron fluence (n/cm^2), Total Ionizing Radiation (Rads (Si)) and Gamma Dose Rate (Rads (Si)/sec). Those tests will be conducted to simulate a realistic controlled environment with the possibility of strong nuclear incidents which could possibly occur.

Testing will be conducted at Rockwell International in Canoga Park (60 Cobalt) and at Rockwell International in Anaheim (Flash x-ray machine). It is anticipated that the series of tests will be spread over approximately three weeks. Figure 3 shows the test set-up and Figure 4 shows radiation hardening test levels. The testing will be conducted in accordance with EIA-455-49 "Procedure for Measuring Gamma Irradiation Effects in Optical Fiber and Optical Cables" (Ref. Appendix 3 of LC-T-94-C027-RF). Change in optical transmittance will be monitored by recording 850 nm signal level before, during and after radiation testing to evaluate how much loss may occur due to the influence of the radiation exposure.

2.8 Environmental: salt spray

The developed feedthrough test units will be evaluated for withstanding exposure to a salt spray environment. The exposure will be made to both Type 1 and Type 2. The test units shall be subjected to 48 hours of salt spray testing in accordance with Standard MIL-STD-202, Method 101, Test Condition B, using a 5 percent by weight salt solution. Immediately after exposure, the exterior surface and the mating face of the test specimens shall be thoroughly washed with tap water. The specimen shall then be dried in a circulating air oven at a temperature of 38° + 30°C (100° +/- 50°F) for a period of 12 hours. The specimen shall then by removed and inspected with 4X magnification and show no evidence of exposure of basis metal nor indication of corrosion products.

Change in Optical Transmittance will be monitored by recording 850 nm signal level before, during and after the salt spray test.

2.9 Environmental: humidity

Type 1 and Type 2 feedthrough units will be tested in a humidity exposure environment. The units will be subjected to 240 hours of exposure to 98-100% humidity at

104°F (+40°C) to 140°F (+60°C) prior to the humidity exposure, the specimens shall be conditioned.

A. Conditioning - Condition specimens at +45°C to +55°C (+113°F to +131°F) for 24 hours and return to room ambient temperature prior to beginning humidity exposure. Measure and record optical transmittance at room ambient temperature before and after conditioning.

B. Exposure - Subject test items to the temperature and humidity conditions described above for 240 hours exposure. Measure and record optical transmittance before, during and after humidity exposure. Record at end of each 24-hour period.

2.10 Environmental: final pressure differential levels

Following all of the environmental and mechanical testing, a repeat of the pressure differential test (helium leaks rate) will be conducted to assure that the testing did not degrade the hermetic sealing of the feedthroughs.

The test procedure is shown in Appendix 5 of LC-T-94-C027-RF with detailed steps for pulling down a vacuum condition on one side of the bulkhead pressure specimen under test, and sensing any leakage of helium. The leak rate, if detectable, is measured in cc/sec of helium.

The blank data sheet in Appendix 5 of LC-T-94-C027-RF should be filled out for each test conducted.

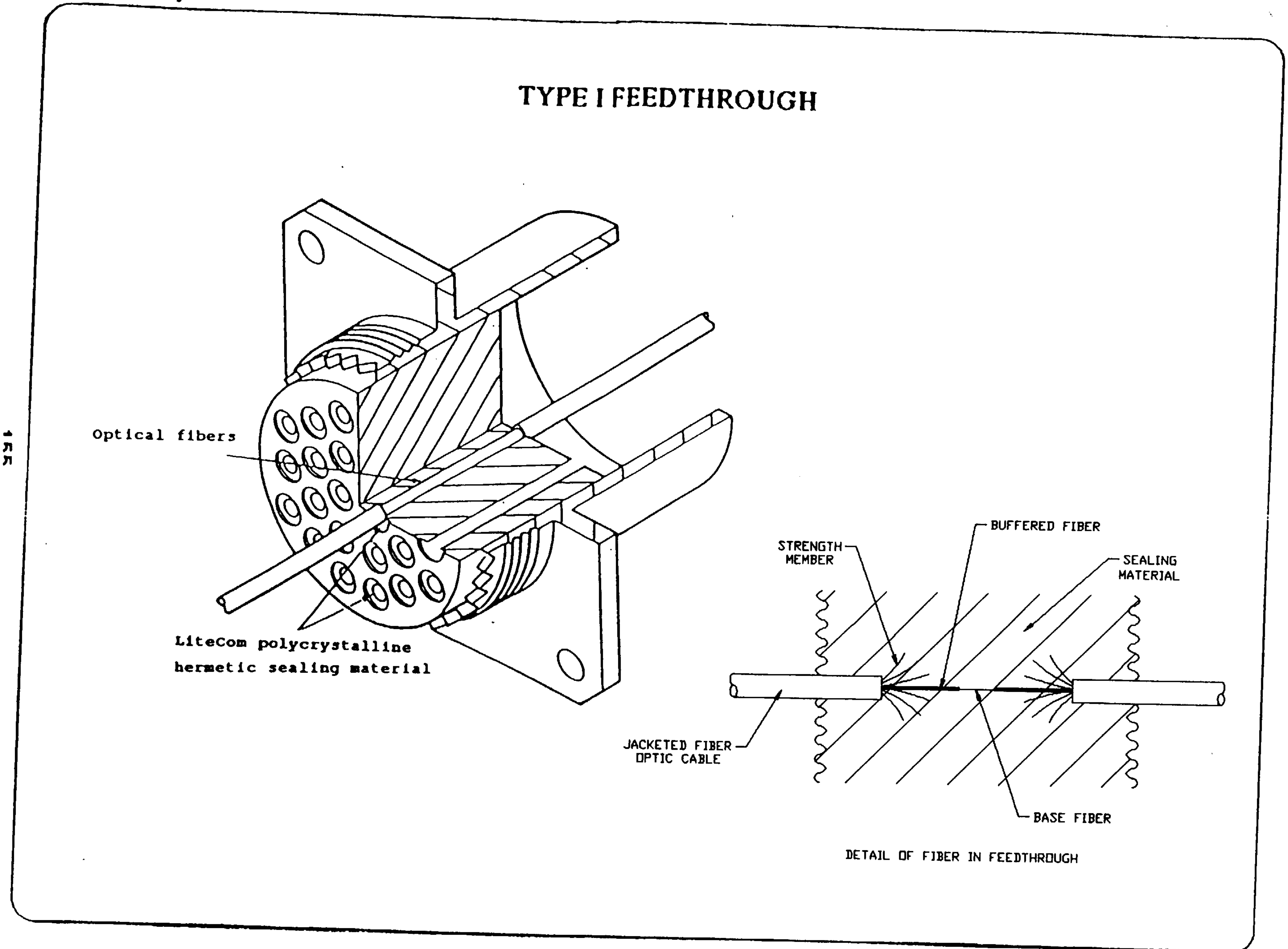


Figure 1 Type I Multi-Channel Feedthrough

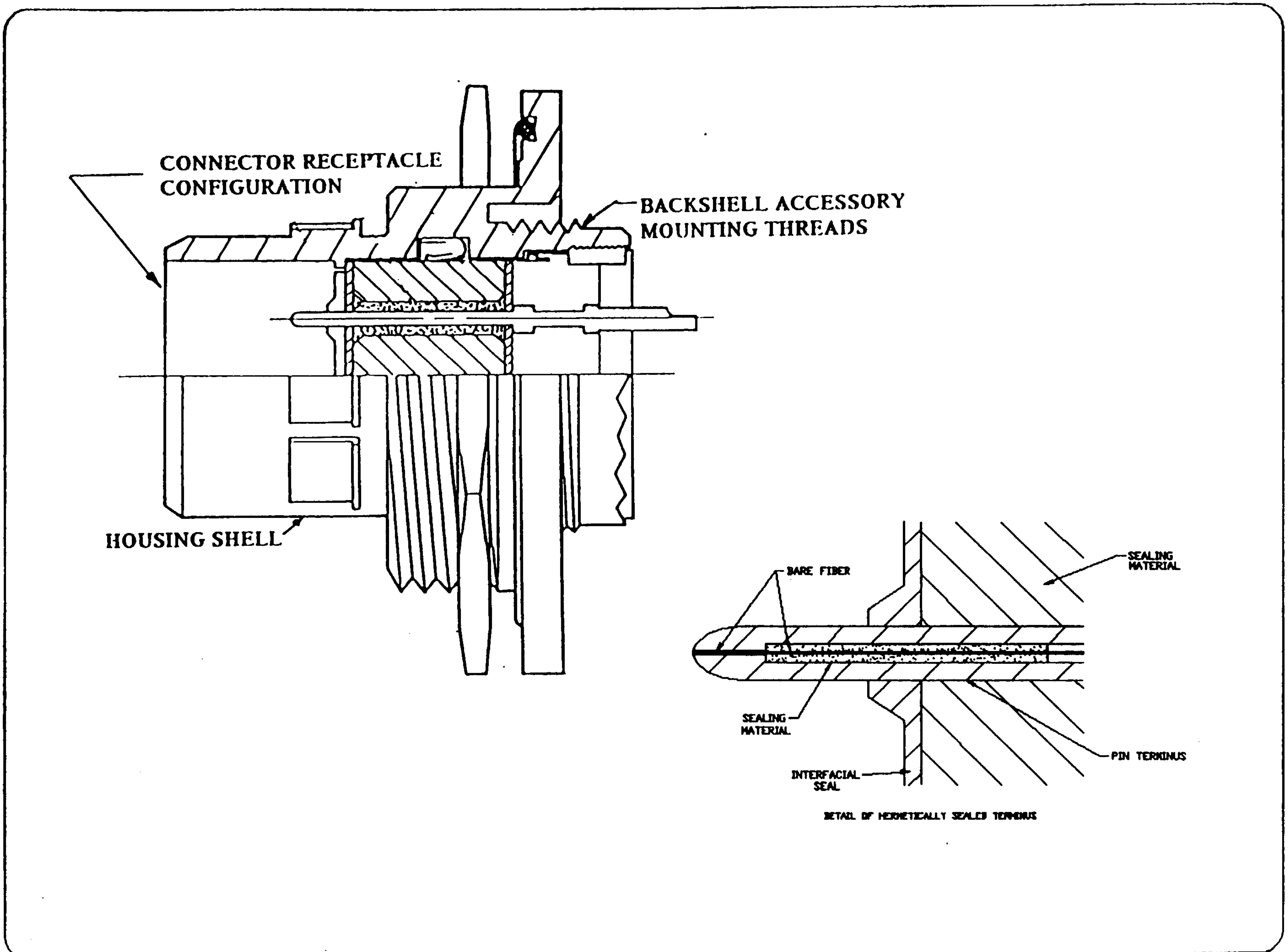


Figure 2 Type II Multi-Channel Feedthrough

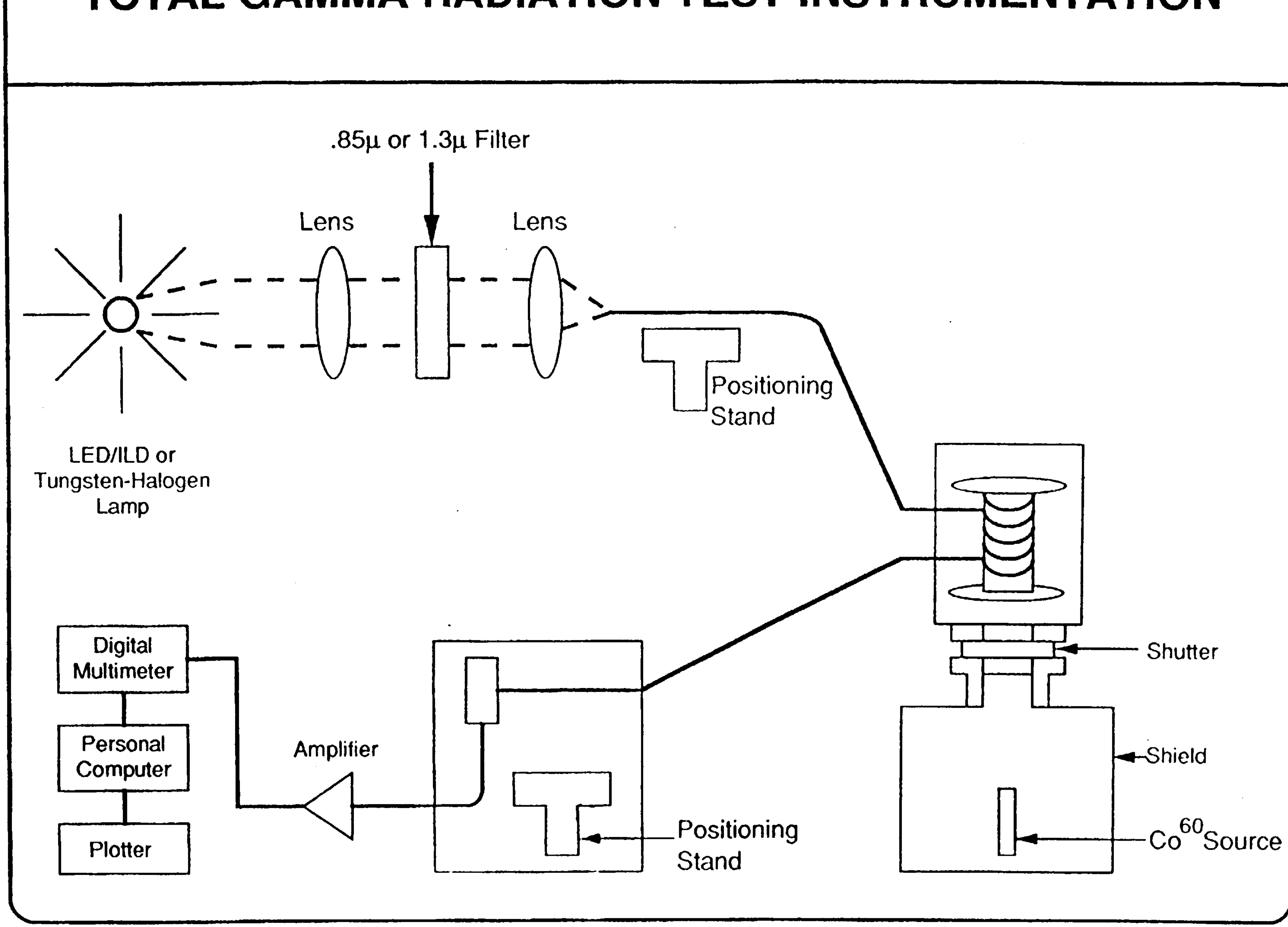


Figure 3 Radiation Test Instrumentation

RADIATION HARDENING
Test Levels

	ELECTRONIC STANDARDS	SYSTEMS	FIBER OPTICS
NEUTRON FLUENCE (n/cm^2)	1×10^{12}	1×10^{12}	1×10^{12}
TOTAL IONIZING RADIATION (Rads(Si))	3,000 10,000 100,000 1,000,000	1,000 3,000 10,000 100,000 1,000,000	3,000 10,000 100,000
GAMMA DOSE RATE (Rads(Si)/sec)	1×10^{8} 1×10^{9}	1×10^{9} 1×10^{12}	1×10^{9}

Figure 4 Radiation Hardening Test Levels

APPENDIX 3

Test Procedure

TABLE OF CONTENTS

Appendix A

Interconnection Device Total Insertion Loss Test

FOTP-34

INTERCONNECTION DEVICE TOTAL INSERTION LOSS TEST

1. INTENT

1.1 The purpose of this test procedure is to determine the loss of fiber optic interconnecting devices intended for single and multichannel and/or hybrid configurations. It establishes the insertion loss as would be experienced in actual usage and may be used for quality assessment purposes.

The procedure is to take measurements from which total insertion loss or decrease in useful power can be calculated.

The methods used in this procedure are designed to provide the total insertion loss as would be experienced at the anticipated extremes of system applications, both short and long length links. Also, a method is provided to identify the intrinsic and extrinsic components of total insertion loss.

1.2 This test will establish insertion losses for:

1.2.1 Method A: Short lengths in which steady state modal conditions do not exist at the interconnection, typically less than 500m to 1 km.

1.2.2 Method B: Long lengths in which steady state modal conditions exist at the interconnection, typically in the range of 500m to 1 km or more.

1.2.3 Method C: User Specified Conditions.

1.2.4 Method D: Interconnection Device Intrinsic/Extrinsic Loss Evaluation.

1.2.5 Method E: Couplers, connectorized cables.

2. TEST EQUIPMENT

2.1 The following test equipment shall be used as required for testing in the configurations as shown.

Optical, mechanical and thermal stability of the test set-up is necessary to facilitate movement of the test set-up enabling the test sample to be subjected to environmental test while monitoring insertion loss.

2.1.1 Light Source - A suitable incoherent light source shall be used, such as an LED. The source shall, at a minimum, have the following parameters.

A. The output radiation pattern shall have a numerical aperture greater than the acceptance NA of the fiber used and a spot diameter greater than the core diameter of the fiber used.

B. Operating wavelength (including device wavelength tolerance) shall be that for the fiber or fibers for which the interconnecting device is intended.

C. The light source must be stable within 1 dB in intensity over a period sufficiently long to allow the measurements to be completed. (NOTE: If insertion loss is monitored while subjecting the sample to environmental test, the period may be several weeks).

2.1.2 Source Monitoring Equipment (SME)

An apparatus capable of monitoring the source output shall be used, allowing corrections to compensate for source output power variations. This may be either a reference fiber or other suitable optical arrangements.

2.1.3 Detection Equipment

The detector and associated electronics shall be capable of measuring all energy exiting from the fiber. They shall be linear at the wavelengths used, and over the expected range of power.

The accuracy of the detection equipment shall be as follows:

Connector Loss	Accuracy
>.5 dB	.1
<.5 dB	.05

2. TEST EQUIPMENT (Continued)

2.1.4 Equilibrium Mode Simulator (EMS)

An apparatus, such as a Mandrel Wrap, or suitable optics capable of simulating within a short fiber the equilibrium mode distribution exiting a long length of fiber under steady state conditions, shall be used where indicated. (Example: Five wraps of 50/125 μm graded index fiber on a 12.7 mm diameter mandrel simulates the far field output radiation pattern of a fiber one kilometer in length).

2.1.5 Cladding Mode Strippers (CMS)

A cladding mode stripper, with a refractive index greater than that of the cladding, shall be used where indicated. Cladding mode stripping shall be applied to fiber areas specified so that remaining cladding energy is substantially down from the core energy as specified by the fiber manufacturer. CMS are used to simulate the attenuation of cladding energy as normally occurs in the first few meters of fiber length.

2.1.6 Optimizing Device

An optimizing device shall be used for intrinsic/extrinsic loss component evaluations. The device shall be able to align two fibers, terminated to optical contacts or bare, with six degrees of freedom (X, Y, Z, two angular, and rotational about the fiber axis). Precision shall be such that well cleaved fibers can be brought into alignment so that coupled energy is back to original, uncut fiber, levels (Fresnel reflection loss accepted at dry interfaces).

3. TEST SAMPLE

A test sample shall consist of mated connector components or a splice, and optical fibers/cables of the length specified for each method.

4. TEST PROCEDURE

Testing should be conducted under Standard Atmospheric Conditions per RS-455 unless otherwise specified in the sectional or detail specification.

4.1 Method A

This method is intended to determine the interconnecting device loss when installed in a short length optical link (non-steady state modal conditions).

4.1.1 The test set-up shall be configured as shown in Figure 1. The sample fiber/cable shall be 4.0 $^{+0}_{-0.5}$ meters long between source and detector. SME shall be installed to continuously monitor the source output.

4.1.2 The light source shall be operated continuous wave or modulated and the initial power (P_o) shall be measured at the detector. The source monitor output power (P_{M1}) shall be measured also.

4.1.3 The sample fiber/cable shall be cut in the center of its length (with ± 25 cm). The installation of each connector or splice shall be accomplished per the manufacturer's specifications.

4.1.4 The connector components shall be mated or the splice completed per the manufacturers specifications, and the power (P_1) present at the detector shall be measured. The source monitor power (P_{M2}) shall be measured also.

4.1 5 Total insertion loss shall be calculated as follows:

$$\text{Loss (dB)} = -10 \log \left[\frac{P_1}{P_o} \times \frac{P_{M2}}{P_{M1}} \right]$$

4.2 Method B

This method is intended to determine the interconnecting device loss when installed in a long length optical link (steady state modal conditions).

4.2.1 Steps 4.1.1 through 4.1.5 shall be followed except the test set-up shall include EMS and CMS and be as configured in Figure 2.

4.3 Method C (User Specified)

This method is intended to determine the interconnecting device loss when installed in an optical link which has parameters as specified in the sectional or detail specification.

4.3.1 The test set-up shall be configured as shown in Figure 3. Each item of test equipment and sample fiber/cable lengths L_1 and L_2 shall be as specified by the user.

4.3.2 The light source shall be operated either continuous wave or modulated as specified by the user, and the initial power level (P_o) shall be measured at the detector. The source monitor (P_{M1}) shall be measured also. A light source may be specified other than as defined in 2.1.1 (e.g., injection laser diode).

4.3.3 The sample fiber/cable shall be cut at the location specified by the user; the installation of each connector or splice shall be accomplished per the manufacturer's specifications.

4.3.4 The connector components shall be mated or the splice completed and the power (P_1) present at the detector shall be measured. The source monitor power (P_{M2}) shall be measured.

4.3.5 Total insertion loss shall be calculated as follows:

$$\text{Loss (dB)} = -10 \log\left[\frac{P_1}{P_o} \times \frac{P_{M2}}{P_{M1}}\right]$$

4.4 Method D

This method is intended to evaluate the interconnecting device intrinsic and extrinsic loss components of total insertion loss and may be used in addition to any of the above methods. Interconnection device intrinsic losses are a function of connector-related parameters. Interconnection device extrinsic losses are a function of fiber/cable parameters beyond the control of the interconnection device design.

4.4.1 After completion of the total insertion loss test, the connectors shall be unmated and disassembled to allow access to the individual optical contacts. (NOTE: Splices and some connector designs may not be capable of disassembly and, therefore, testing per Method D should be performed prior to termination).

4.4.2 Using manipulative stages, optimize the alignment of opposing fibers by obtaining a maximum power output (P_2) at the detector.

4.4.3 Calculate the interconnection extrinsic loss (fiber intrinsic) as follows:

$$\text{Loss (dB)} = -10 \log \frac{P_2}{P_o}$$

(NOTE: Correct for source power output variation).

4.4.4 Fiber core irregularities (e.g., ellipticity) can be identified by repeating step 4.4.2 at a minimum of two rotational positions (about the fiber axis) of opposing fibers.

4.4.5 Calculate the connector intrinsic loss as follows:

$$\text{Loss (dB)} = \begin{bmatrix}\text{Total} \\ \text{Insertion Loss}\end{bmatrix} - \begin{bmatrix}\text{Maximum Interconnection} \\ \text{extrinsic Loss}\end{bmatrix}$$

$$\text{Loss (dB)} = \left[-10 \log \frac{P_1}{P_o}\right] - \left[-10 \log \frac{P_2}{P_o}\right]_{\text{maximum}}$$

(NOTE: Correct for source power output variation).

4.5 Method E

- Later - (To be written)

5. DOCUMENTATION

Data sheets shall contain:

a. Title of test, date, and name of operator
b. Sample description - include termination procedure if applicable
c. Test equipment used and date of latest calibration. Including technical description of each item (i.e., wavelength, NA)
d. Test method designation letter (1.3)
e. Values and observations
   (1) Initial and final measurements
   (2) Calculated losses

6. SUMMARY

The following details shall be specified in the applicable Sectional or Detail interconnecting device specification.

a. Test method designation letter (1.2) (NOTE: For Test Method C, all parameters must be specified, See 4.3).

b. Fiber and cable type to be used.

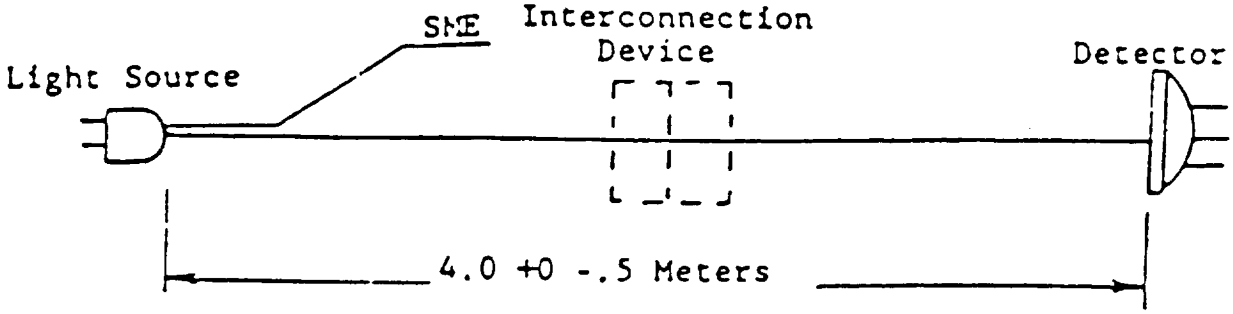


Figure 1

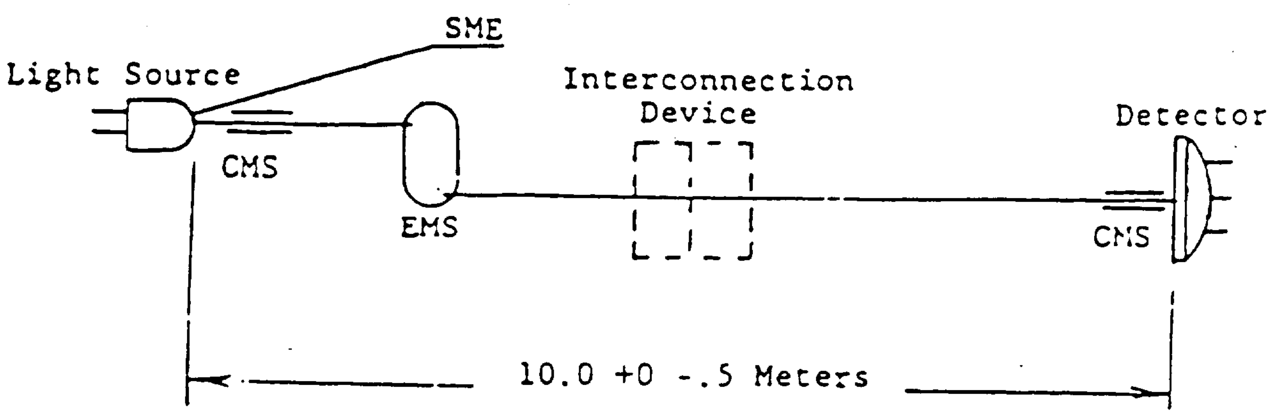


Figure 2

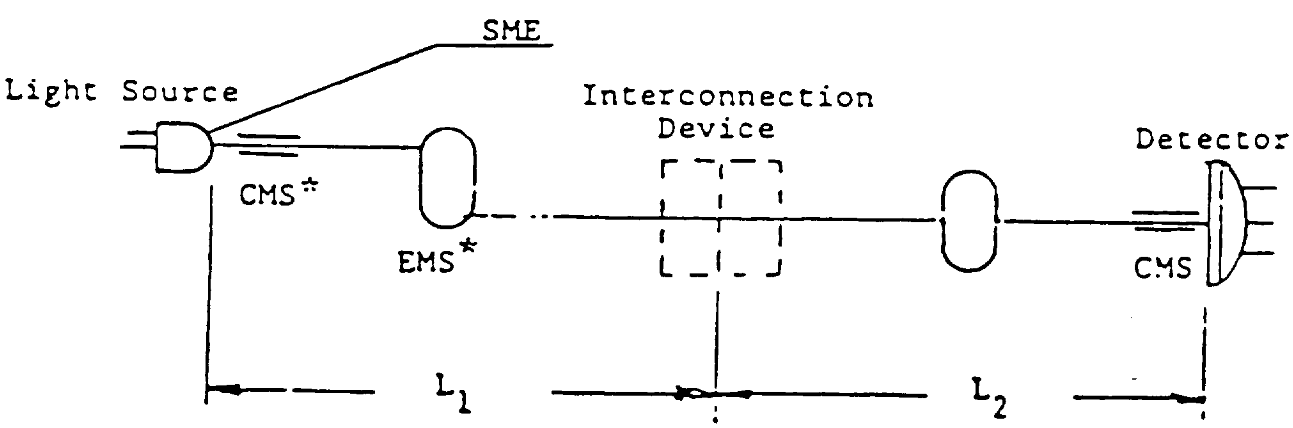


Figure 3

* ptional

Appendix C

Measurement of Change in Optical Transmittance

FOTP-20

MEASUREMENT OF CHANGE IN OPTICAL TRANSMITTANCE

(From EIA Standards Proposal No. 1344-B, formulated under the cognizance of EIA P-6.4 Working Group on Fiber Optic Test Methods and Instrumentation.)

This FOTP forms a part of the latest revision of EIA Recommended Standard RS-455.

1. INTENT

The intent of this procedure is to provide a uniform method for monitoring and measuring the change in optical transmittance of a passive device undergoing a test described in another procedure, hereafter called the primary FOTP, which may invoke its use.

2. TEST EQUIPMENT

The apparatus shall consist of test beds, chambers, or other equipment as specified by the primary FOTP, plus components capable of providing the functions illustrated in Figure 1.

2.1 Optical Power Source

The optical power source shall consist of: a light source emitting wavelengths suitable for the fibers and devices to be tested, and either modulated or unmodulated according to the primary FOTP or the Detail Specification; wavelength-selective optical filters if necessary to limit optical bandwidth; and auxiliary optics as needed to provide illumination of variable spot size and numerical aperture as described in FOTP-50, "Light Launch Conditions for Long Length Graded-Index Optical Fiber Spectral Attenuation Measurements". A light-emitting diode (LED) or injection laser with a suitable radiation band is a convenient source, and may be specified.

2.2 Optical Power Divider

The optical power divider shall be capable of dividing power in predetermined ratios which remain constant over the course of the test independent of input power or external influences. The splitting factors need not be equal; in fact, lowest detector error will be achieved when the power into the test fiber is increased to compensate for losses in the device under test. Any of several commercially available "star" couplers, two-channel couplers, or custom made devices are suggested.

The optical power source and divider may be combined within a single unit.

2.3 Mode Filters

Mode filters that remove optical power in cladding and lossy (overfilled) core modes should be installed near the input end of the reference, monitor and test sample fibers, after the power divider, unless otherwise specified. When an insertion loss test is called out by a Sectional or Detail Specification, the same modal conditions as specified by FOTP-34, "Interconnection Device Total Insertion Loss Test", for the insertion loss test shall be used for both tests.

Mode filters may be established as described in FOTP-50; FOTP-50 may also serve as a guide for determining mode filters for other fiber classes.

Two possible configurations that may be used as mode filters are sketched in Figure 2. In the first arrangement, the fiber or cable is wrapped helically around a rod, and in the second, it is placed in an "S" shape channel. In the latter setup, the fiber is often stripped to its primary optical cladding and the channel filled with liquid of refractive index greater than that of the cladding. In any case, the specific dimensions of the filter will depend on the characteristics of the fiber or cable used and may be determined using the methods described in FOTP-50.

2.4 Detectors

Each detector shall be: of sufficient active area and placed sufficiently close to the end of the fiber to detect all the radiation emitted from it; of the same manufacturer and model; and linear within 3%, unless otherwise specified, over the range of optical powers to be encountered. The individual detectors need not be matched in peak responsivity, nor calibrated absolutely, as long as linearity can be assured.

For unmodulated signals, photovoltaic PIN diodes are recommended because of their linearity and low dark current. These should operate into well-filtered electronics to minimize noise.

For modulated signals, photoconductive PIN diodes are recommended because of their low noise and good frequency response. These should operate into tuned electronics to reduce noise. For maximum signal to noise ratio, synchronous detection techniques may be employed.

2.5 Electronic Instruments

Instrument output may be analog or digital. Readout devices or recording devices, or both, may be multiple-record or ratio, although the latter is more convenient. Suggested devices for conversion of the detector outputs to a ratio include digital voltmeters or lock-in amplifiers with ratio capability, voltage divider modules, ratio amplifiers, and A/D converters with provision for an external reference intput.

3. TEST SAMPLE AND REFERENCE SAMPLE

The test sample may be any configuration of connectors, other devices, cables, and perhaps mode filters, as specified by the primary FOTP.

The reference sample shall be identical to the test sample except that the device under test shall not have been installed. This reference sample shall be positioned as closely as possible to the test sample, especially where the latter passes through a test bed that may subject it to physical, environmental, or other changes.

The monitor fiber, when included, may be of any convenient length, but must be protected from any environmental or other variations that might change its attenuation.

Since the method assumes that optical power division among the test, reference, and monitor samples and the fractional power received from them by each detector remains constant with time, these samples must be left optically connected to the optical power divider and to the detectors throughout the test sequence of the primary FOTP unless it is specifically required otherwise.

4. TEST PROCEDURE AND CALCULATIONS

4.1 Test Procedure

Signal (ratio) readings shall be taken before, during, and after the test sequence, as specified in the primary FOTP. The initial reading shall be labeled with the subscript o (zero), and subsequent readings throughout a given sequence with the subscripts 1, 2, 3, ..., i, ... If required by the primary FOTP, each of these recorded readings may be an average of several individual ones.

If ratio devices are not available, the outputs of the separate detectors may be recorded with the additional subscripts t and r (see Figure 1).

If a monitor fiber is called out by the primary FOTP or Detail Specifications, additional readings from its detector shall be taken at each step of the sequence and appropriately labeled.

4.2 Calculations

If detector outputs are measured separately, changes in optical transmittance during the test sequence, ΔD_i, may be calculated from the equation:

$$\Delta D_i = 10 \log (S_{ti}/S_{ri}) - 10 \log (S_{to}/S_{ro}), \quad (1)$$

in which the various "Ss" are the readings recorded in paragraph 4.1. This equation is developed in Appendix A.

If ratio circuits are used so that the recorded signals are $S_i = S_{ti}/S_{ri}$, then the simpler equation

$$\Delta D_i = 10 \log S_i - 10 \log S_o = 10 \log (S_i/S_o) \quad (2)$$

may be used in the calculations.

With the sign convention adopted in this procedure, a decrease in transmitted optical power (increased loss in the device under test) will result in a negative value for the calculated ΔD_i.

4.3 Optical Monitor Fiber

The basic apparatus inherently provides a measurement of transmittance changes in the device under test corrected for any changes that might occur in either the source or those parts of the test sample not included in the device. It does not, however, provide a measurement of these last two. When such information is required, the use of an auxiliary fiber to directly monitor source fluctuations will be called for in the primary FOTP or Detail Specification. In this case, transmittance changes in the reference sample may be calculated by using the ratios S_{ri}/S_{mi} in Equations (1) or (2) of paragraph 4.2.

5. DOCUMENTATION

In addition to the documentation required by the primary test procedure, the data sheets shall contain:

5.1 Date and name of operator.

5.2 Device characteristics or model number of source (including center wavelength and spectral width), splitter, detector, and all other electronic equipment used to make the measurements.

5.3 Date of latest calibration of all instruments.

5.4 Method of coupling optical power from the source to the splitter, from the splitter to the test, reference and monitor fibers, and from the fibers to the detectors.

5.5 Drive current of source and important operating levels of other instruments.

5.6 All measurements in tabular or graphical form.

6. SUMMARY

In addition to the details required by the primary test procedure, the following shall be reported:

6.1 Calculated changes in optical transmittance of the device under test at each step in the test sequence (see paragraph 4.2).

6.2 When required, calculated changes in optical transmittance of the reference sample (see paragraph 4.3).

Appendix D

Temperature Cycling (Temperature Shock)

FOTP-3

TEMPERATURE CYCLING (THERMAL SHOCK)

1. INTENT

1.1 The intent of this test is to determine the effect of temperature cycling on the optical and mechanical characteristics of fiber optic connectors. This test should be performed only on connectors designed to meet such requirements. This test procedure is intended to simulate the worst probable conditions of storage, transportation, and application. Effects of thermal shock include cracking and delamination of finishes, cracking and crazing of enbedding and encapsulating compounds, opening of thermal seals and case seams, leakage of filling materials, rupturing or cracking of hermetic seals and vacuum glass to metal seals and changes of optical characteristics due to mechanical displacement or rupture of fibers.

1.2 Typical indications of damage resulting from this test are:

(A) Inability to unmate or mate

(B) Broken parts or accessories

(C) Damage to seals

(D) Optical degradation through misalignment, etc.

2. TEST EQUIPMENT

2.1 Test Chambers

Separate chambers shall be used for the extreme temperature conditions of steps 1 and 3, Table I. The air temperature of the two chambers shall be held at each of the extreme temperatures by means of circulation and sufficient hot- or cold-chamber thermal capacity so that the ambient temperature shall reach the specified temperature within 2 minutes after the specimens have been transferred to the appropriate chamber.

3. TEST SAMPLE

3.1 Sample and Fixture

A test sample shall consist of a plug, a receptacle, or a mated plug and receptacle as specified. Unless otherwise specified, the test sample shall be assembled with contact wires, fibers and sealing plugs, before, during, and after the test. The cable shall be of sufficient continuous length to interconnect the test connector and test equipment, as may be specified. Connectors not normally equipped with an integral coupling device shall be maintained in the simulated mated condition by a suitable fixture. The fixture shall be made as lightweight as possible in order to reduce "heat sink" effects that would reduce the severity of thermal shock.

3.2 Sample Preparation

The test samples shall be preconditioned at room temperature and approximately 50% relative humidity for 24 hours prior to the test.

4. TEST PROCEDURE

The connector assembly operating conditions during the exposure shall be specified.

4.1 Initial and Final Measurements

Specified measurements shall be made prior to the first cycle and upon completion of the final cycle, except that failures shall be based on measurements made after the specimen has returned to thermal stability at room ambient temperature following the final cycle.

4.2 Sample Mass Determination

Before cycling, the combined mass of the assembly (mated, if applicable) to be tested shall be determined. This mass shall include contacts, sealing rings, connector accessories attached to the connector, and any wire and fiber within the envelope boundaries of the connector. The mass of any fixutre used to hold the connectors in the mated condition shall also be determined. The mass of the specimen is the total mass of the mated assembly and any fixture attached to the connector.

4.3 Number of Cycles

Specimens shall be placed in such a position with respect to the airstream that there is substantially no obstruction to the flow of air across and around the specimen. When special mounting is required, it shall be specified. The specimen shall then be subjected to the specified test condition of Table I. The first five cycles shall run continuously. After five cycles, the test may be interrupted after the completion of any full cycle, and the specimens allowed to return to room ambient temperature before test is resumed.

4.3 Number of Cycles (continued)

One cycle consists of steps 1 through 4 of the applicable test condition. Specimens shall not be subjected to forced circulating air while being transferred from one chamber to another. Direct heat conduction to the specimen should be minimized.

TABLE 1

TEMPERATURE CYCLING

Step	Test Condition	Number of Cycles
	A A-1 A-2 A-3	5 25 50 100
	Temperature (^{o}C)	Time (Minutes)
	*(for low test temperature)	
1	See individual spec.*	See Table 2
2	25 ± 10	5 max
3	See individual spec.*	See Table 2
4	25 ± 10	5 max
	*(for high test temperature)	

4.4 Exposure Time at Temperature Extremes

The connector samples shall be subjected to the temperature extremes for one of the durations of Table 2. The duration of the test and length of exposure are standardized for a given mass of the test item. This approach allows the connector to reach thermal stability at the temperature of the test chamber while keeping the testing time to a minimum.

TABLE 2

EXPOSURE TIME AT TEMPERATURE EXTREMES

Mass of Specimen	Minimum Time (for steps 1 and 3)
28 grams (1 oz) and below	1/2 hour or 1/4 when specified
Above 28 grams to 136 grams inclusive	1/2 hour
Above 136 grams to 1.36 kilograms inclusive	1 hour
Above 1.36 kilograms to 13.6 kilograms incl.	2 hours
Above 13.6 kilograms to 136 kilograms incl.	4 hours
Above 136 kilograms	8 hours

5 DOCUMENTATION

The data sheets sheets shall contain:

(A) Title of test, date and name of operator.

(B) Sample description - include fixture, if applicable.

(C) Test equipment used and date of latest calibration.

(D) Test procedure.

(E) Values and observations

(1) Visual examination

(2) Monitoring measurements as required by individual specification

(3) Insertion loss measurements

(4) Assembly mass (see 4.2)

(5) Initial and final measurements (see 4.1)

6. SUMMARY

The following details shall be specified in the individual specification:

(A) Mated or unmated state of the test connectors, assembly of test sample if other than 3.1 and test equipment interconnect (see 3.1).

(B) Test condition letter (see 4.3).

(C) Special mounting, if applicable (see 4.3).

(D) Load conditions if applicable.

(E) Temperature extremes of test chambers (see 4.3).

(F) Observations or measurements to be made before, during and after testing (see 4.).

(G) The failure criteria and methods for measuring insertion loss.

(H) Initial and final measurements (see 4.1).

Appendix E

Vibration Testing

VIBRATION TEST PROCEDURE FOR FIBER OPTIC CONNECTING DEVICES
(Ref. EIA FOTP-11)

1. INTENT

1.1 The intent of this test is to determine the effects of vibration within the sinusoidal and random vibration environments that may be encountered during the life of the fiber optic connector. Typical indications of damage resulting from this test are:

Inability to mate or unmate, broken parts or accessories, transmission loss, damage to seals.

2. TEST EQUIPMENT

2.1 The vibration system consisting of the vibration machine, together with its auxiliary test equipment, shall be capable of generating either a sinusoidal or random excitation. Test equipment for random vibration shall produce random excitation that possesses a gaussian (normal) amplitude distribution, except that the acceleration magnitudes of the peak values may be limited to a minimum of three times the rms (three-sigma [σ] limits).

3. TEST SAMPLE

3.1 Type of Sample

A vibration test sample shall be defined as a fully terminated connector and associated hardware.

3.2 Preparation

Each test sample shall be prepared with wave guide and other materials or processes, simulating field usage of the connector. If normal connector mating depends upon forces external to the connector, such forces and mounting arrangements shall be duplicated as closely as possible. If mating is achieved by normal locking means, then only normal locking means shall be used. Test samples shall be visually examined for chips, cracks, tears, loose or missing parts, proper lubrication, proper assembly and mate-ability. Unless otherwise specified, the test sample shall be terminated with fiber of the type and configuration which is specified by the applicable detail specification, or if not on the detail specification by that recommended by the connector manufacturer.

3. TEST SAMPLE (continued)

3.3 Method of Mounting

The connector test specimen shall be attached to a fixture capable of transmitting the vibration conditions specified. The test fixture shall be designed such that resonant vibration inherent in the fixture within the frequency range specified shall be minor. The magnitude of the applied vibration shall be monitored on the test fixture near the specimen mounting points. The test specimen shall be mounted rigidly to the test fixture and simulate as closely as possible the normal mounting of the connector. A minimum of 7.874 inches (20 centimeters) of fiber optic cable shall be unsupported on both ends of the connector and attached to vibrating surface. For specimens with attached brackets, one of the vibration-test directions shall be parallel to the mounting surface of the bracket. Vibration input shall be monitored on the mounting fixture in the proximity of the support points of the specimen.

4. TEST PROCEDURES

Tests and measurements before, during, and after vibration shall be as required in the detail specification.

4.1 Test Conditions I, II, III, and IV (Sinusoidal Vibration)

4.1.1 Sinusoidal Vibration Conditions

Vibration conditions shall be in accordance with Table I and Figure 1, as applicable.

TABLE I

VIBRATION CONDITIONS

Test Condition	Frequency Range	Peak g level
I	Low - 10 to 55	
II	High - 10 to 500	10
III	High - 10 to 2,000	15
IV	High - 10 to 2,000	20

4. TEST PROCEDURES (continued)

4.1.2 Resonance

A critical resonant frequency is that frequency at which any point on the specimen is observed to have a maximum amplitude more than twice that of the support points. When specified, resonant frequencies shall be determined either by monitoring parameters such as terminus separation, or by use of resonance-detecting instrumentation.

4.1.3 Test Condition I

The specimens shall be subjected to a simple harmonic motion having an amplitude of .030 inches (0.76 mm) (1.52 mm maximum total excursion), the frequency being varied uniformly between the approximate limits of 10 and 55 Hz. The entire frequency range, from 10 to 55 Hz and return to 10 Hz, shall be traversed in approximately one minute. Unless otherwise specified, this motion shall be applied for 2 hours in each of three mutually perpendicular directions (total of 6 hours). If applicable, this test shall be made under load conditions.

4.1.4 Test Condition II (10g peak)

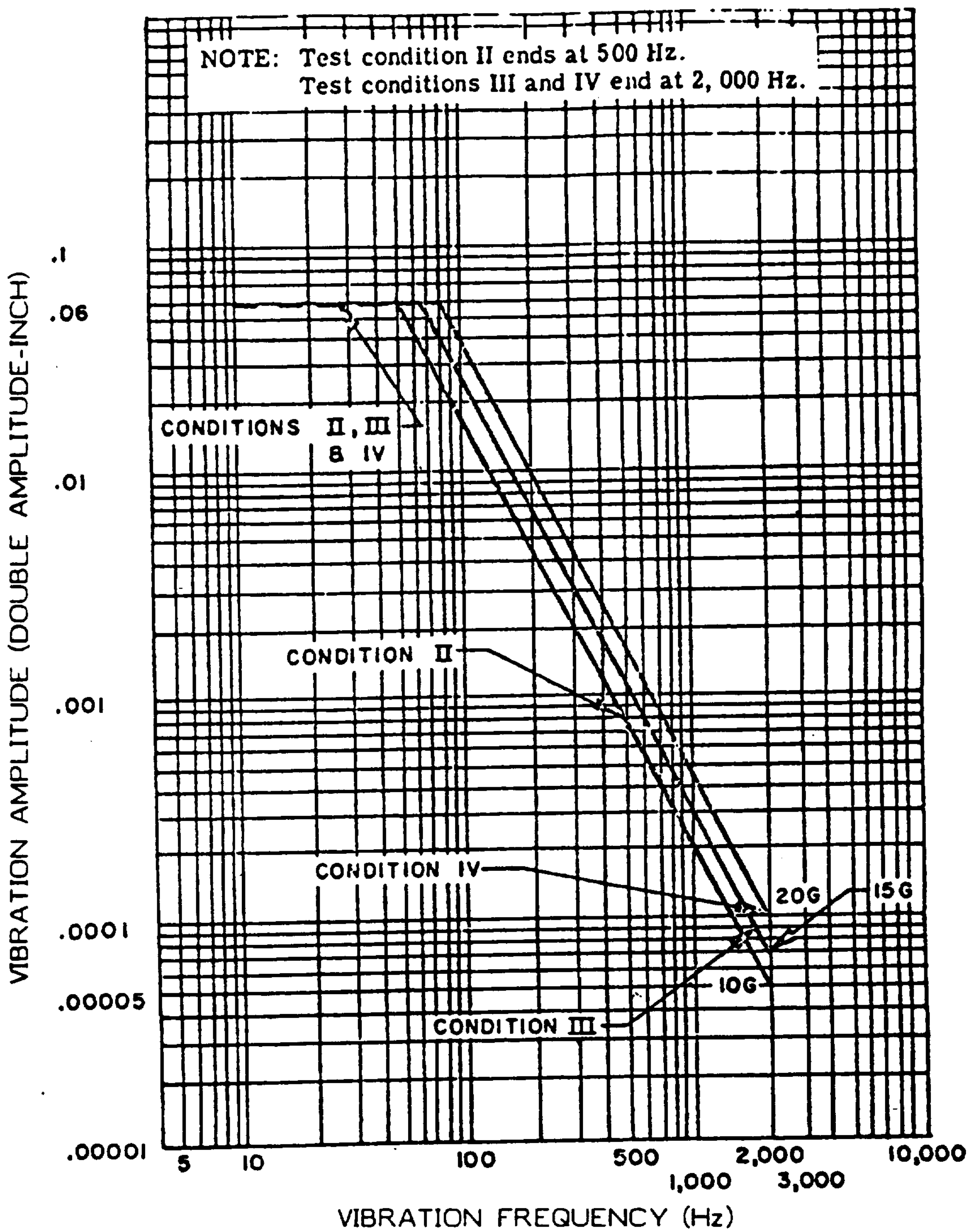
The specimens, while deenergized or operating under the load conditions specified, shall be subjected to the vibration amplitude, frequency range, and duration specified in 4.1.4.1, 4.1.4.2, and 4.1.4.3, respectively (see Figure 1).

4.1.4.1 Amplitude

The specimens shall be subjected to a simple harmonic motion having an amplitude of either .060 inches (1.52 mm) double amplitude (maximum total excursion) or 10 gravity units (g peak), whichever is less. The tolerance on vibration amplitude shall be ± 10%.

4.1.4.2 Frequency Range

The vibration frequency shall be varied logarithmically between the approximate limits of 10 and 500 Hz except that the procedure (see 4.1.3) of this Standard may be applied during the 10 to 55 Hz band of the vibration frequency range.



G = $.0512f^2DA$ (f^2 = frequency in hertz, DA = double amplitude in inches.)

FIGURE 1

Vibration Test Curves - High Frequency

4. TEST PROCEDURES (continued)

4.1.4.3 Sweep Time and Duration

The entire frequency range of 10 to 500 Hz and return to 10 Hz shall be traversed in 15 minutes. This cycle shall be performed 12 times in each of three mutually perpendicular directions (total of 36 times), so that the motion shall be applied for a total period of approximately 9 hours. Circuit interruptions in vibration sequence are permitted provided the requirements for rate of change and test duration are met. Completion of cycling within any separate band is permissible before going to the next band. When the procedure (see 4.1.3) is used for the 10 to 55 Hz band, the duration of this portion shall be the same as the duration for this band using logarithmic cycling (approximately 1-1/3 hours in each of three mutually perpendicular directions).

4.1.5 Test Condition III (15g peak)

The specimens, while deenergized or operating under the load conditions specified, shall be subjected to the vibration amplitude, frequency range, and duration specified in 4.1.5.1, 4.1.5.2, and 4.1.5.3, respectively (see Figure 1).

4.1.5.1 Amplitude

The specimens shall be subjected to a simple harmonic motion having an amplitude of either .060 inches (1.52 mm) double amplitude (maximum total excursion) or 15g (peak), whichever is less. The tolerance on vibration amplitude shall be ± 10%.

4.1.5.2 Frequency Range

The vibration frequency shall be varied logarithmically between the approximate limits of 10 to 2,000 Hz except that the procedure (see 4.1.3) of this Standard may be applied during the 10 to 55 Hz band of the vibration frequency range.

4.1.5.3 Sweep Time and Duration

The entire frequency range of 10 to 2,000 Hz and return to 10 Hz shall be traversed in 20 minutes. This cycle shall be performed 12 times in each of three perpendicular directions (total of 36 times) so that the motion shall be applied for a total of approximately 12 hours.

4.1.5.3 (continued)

Interruptions are permitted provided the requirements for rate of change and test duration are met. Completion of cycling within any separate band is permissible before going to the next band. When the procedure (see 4.1.3) of this Standard is used for the 10 to 55 Hz band, the duration of this portion shall be the same as the duration for this band using logarithmic cycling (approximately 1-1/3 hours in each of three mutually perpendicular directions).

4.1.6 Test Condition IV (20g peak)

The specimens, while deenergized or operating under the load conditions specified, shall be subjected to the vibration amplitude, frequency range, and duration specified in 4.1.6.1, 4.1.6.2, and 4.1.6.3, respectively (see Figure 1).

4.1.6.1 Amplitude

The specimens shall be subjected to a simple harmonic motion having an amplitude of either .060 inches (1.52 mm) double amplitude (maximum total excursion) or 20g (peak), whichever is less. The tolerance on vibration amplitude shall be ± 10%.

4.1.6.2 Frequency Range

The vibration frequency shall be varied logarithmically between the approximate limits of 10 to 2,000 Hz.

4.1.6.3 Sweep Time and Duration

The entire frequency range of 10 to 2,000 Hz and return to 10 Hz shall be traversed in 20 minutes. This cycle shall be performed 12 times in each three mutually perpendicular directions (total of 36 times), so that the motion shall be applied for a total period of approximately 12 hours. Interruptions are permitted provided the requirements for rate of change and test duration are met. Completion of cycling within any separate band is permissible before going to the next band. When the procedure (see 4.1.3) of this Standard is used for the 10 to 55 Hz band, the duration of this portion shall be the same as the duration for this band using logarithmic cycling (approximately 1-1/3 hours in each of three mutually perpendicular directions).

4. TEST PROCEDURES (continued)

4.2 Test Conditions V and VI (Random Vibration)

4.2.1 Control and Analysis of Random Vibration

4.2.1.1 Spectral-Density Curves

The output of the vibration machine shall be presented graphically as power-spectral density versus frequency. (1/) The spectral-density values shall be within +40 and -30% (±1.5 dB) of the specified values between a lower specified frequency and 1,000 Hz, and within +100 and -50% (±3 dB) of the specified values between 1,000 and an upper specified frequency. A filter bandwidth will be a maximum of 1/3-octave or a frequency of 25 Hz, whichever is greater.

1/ Power-spectral density is the mean-square value of oscillation passed by a narrow-band filter per unit-filter bandwidth. For this application it is expressed as G^2/f where G^2/f is the mean-square value of acceleration expressed in gravitational units per number of cycles of filter bandwidth. The spectral-density curves are usually plotted either on a logarithmic scale, or in units of decibles (dB). The number of decibles is defined by the equation:

$$dB = 10 \log \frac{G^2/f}{G_r^2/f} = 20 \log \frac{G/\sqrt{f}}{G_r/\sqrt{f}}$$

The rms value of acceleration within a frequency band between f_1 and f_2 is:

$$G_{rms} = \left[\int_{f_1}^{f_2} G^2/f \; df \right]^{1/2}$$

where G_r^2/f is a given reference value of power-spectral density, usually the maximum specified value.

4.2.1.2 Distribution Curves

A probability density-distribution curve may be obtained and compared with a gaussian-distribution curve. The experimentally obtained curve shall not differ from the gaussian curve by more than ±10% of the maximum value.

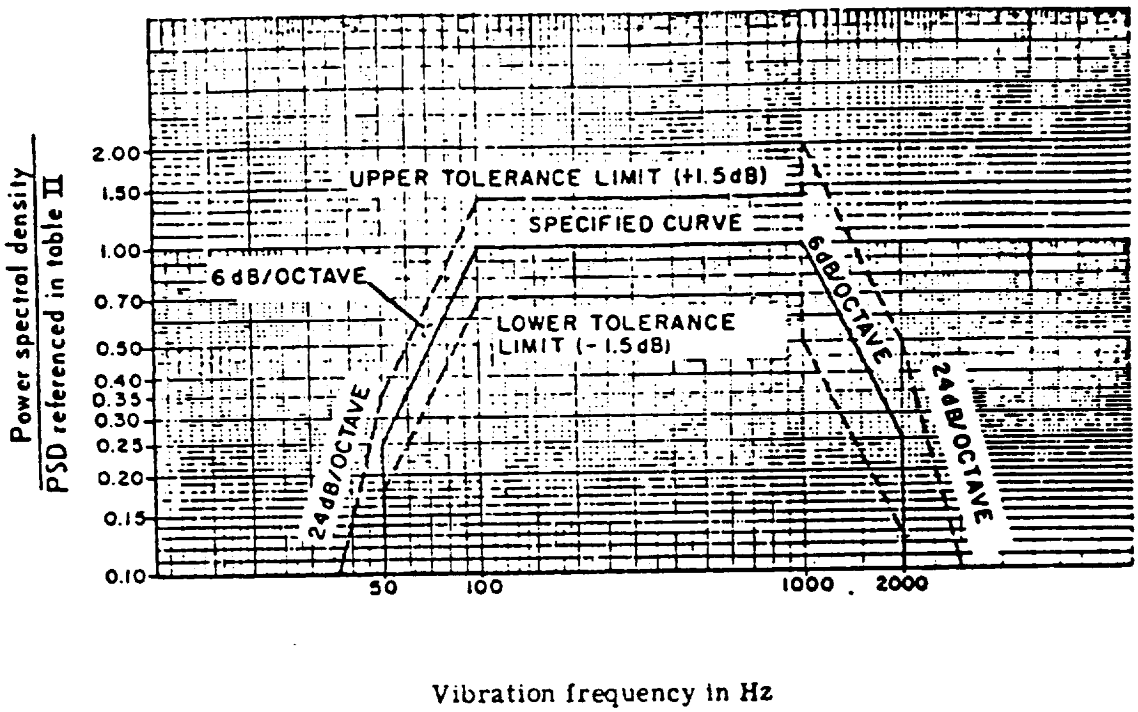


TABLE II. Values for test-condition I 1/

Characteristics		
Test condition letter	Power spectral density	Overall rms G
A	.02	5.2
B	.04	7.3
C	.06	9.0
D	.1	11.6
E	.2	16.4
F	.3	20.0
G	.4	23.1
H	.6	28.4
J	1.0	36.6
K	1.5	44.8

1/ For duration of test, see 4.2.2.

FIGURE 2. Test condition V random vibration test-curve envelope (see table II).

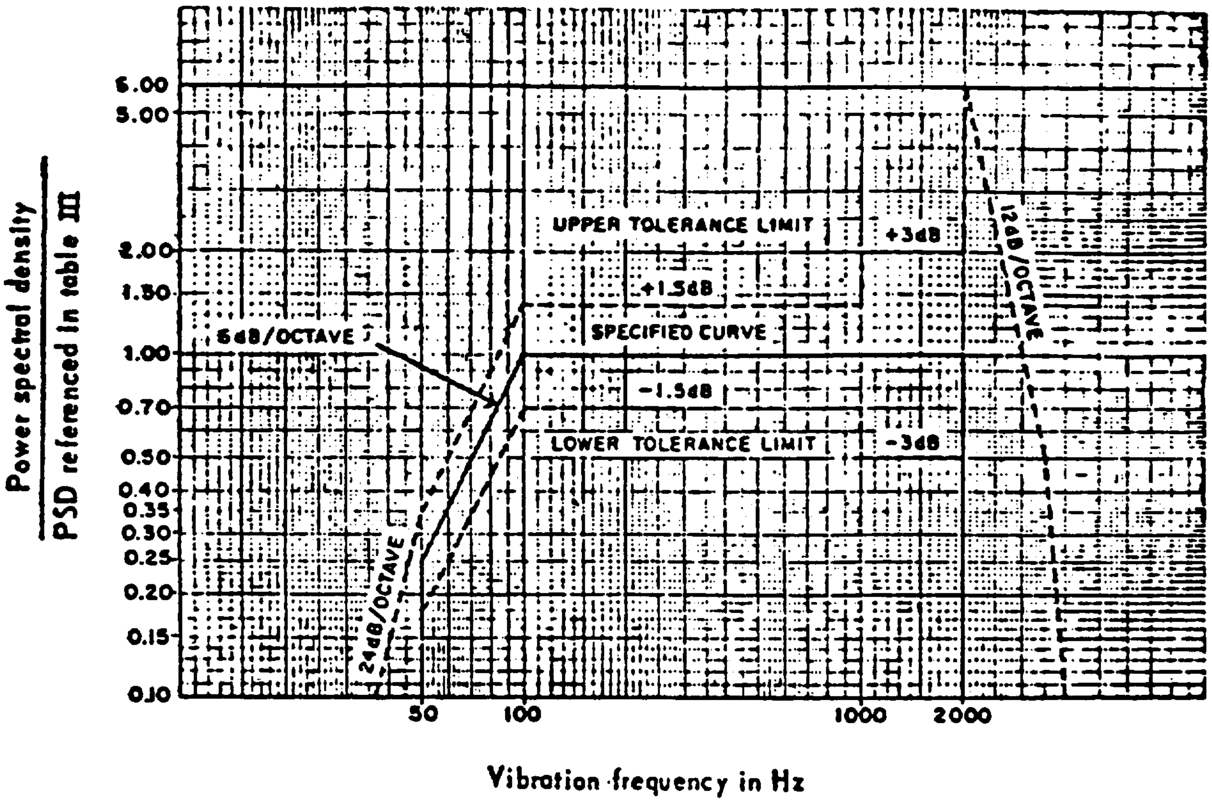


TABLE III. Values for test-condition VI 1/

Characteristics		
Test condition letter	Power spectral density	Overall rms G
A	.02	5.9
B	.04	8.3
C	.06	10.2
D	.1	13.2
E	.2	18.7
F	.3	22.8
G	.4	26.4
H	.6	32.3
J	1.0	41.7
K	1.5	51.1

1/ For duration of test, see 4.2.2.

FIGURE 3. Test condition VI, random vibration test-curve envelope (see table III).

4.2.1.3 Monitoring

Monitoring involves measurements of the vibration excitation and of the test-item performance. When required in the individual specification, the specimen may be monitored during the test. The details of the monitoring circuit, including the method and points of connection to the specimen, shall be specified.

4.2.1.4 Vibration Input

The vibration magnitude shall be monitored on a vibration machine, on mounting fixtures, at locations that are as near as practical to the test-item mounting points. When the vibration input is measured at more than one point, the minimum input vibration shall normally be made to correspond to the specified test curve (see Figures 2 and 3). For massive test-items and fixtures, and for large-force exciters or multiple-vibration exciters, the input-control value may be an average of the average magnitudes of three or more inputs. Accelerations in the transverse direction, measured at the test-item attachment points, shall be limited to 100% of the applied vibration. The number and location of the test points shall be specified.

4.2.2 Procedure

The specimen, or substitute equivalent mass, shall be mounted in accordance with 3.3 and the monitoring equipment attached, if applicable, in accordance with 4.2.1.3. The vibration machine shall then be operated and equalized or compensated to deliver the required frequencies and intensities conforming to the curves specified in Test Condition V, Figure 2, or Test Condition VI, Figure 3. The specimen shall then be subjected to the vibration specified by the test-condition letter (see Tables II and III) for the duration as specified: 3 minutes; 15 minutes; 1-1/2 hours; or, 8 hours, in each of three mutually perpendicular directions, and in the order specified (see 3.3) as applicable. The measurements made before, during, and after the test shall be specified and if the specimen is to be monitored during the test, the details shall be in accordance with 4.2.1.4.

5. DOCUMENTATION

5.1 Data sheets shall contain:

A. Title of test, date, and names of personnel.

B. Sample description - include fixture.

C. Test equipment used and date of latest calibration.

D. Test procedure.

E. Values and observations.

6. SUMMARY

6.1 The following details shall be specified in the individual specification:

A. Type and number of samples (see 3.1).

B. Method of mounting (see 3.3).

C. Tests or measurements before, during, and after vibration (see 4.).

D. Method of determining resonance, if applicable (see 4.1.2).

Appendix F

Shock Testing

FOTP-14

FIBER OPTIC SHOCK TEST
(SPECIFIED PULSE)

(From EIA Standards Proposal No. 1337-A, formulated under the cognizance of EIA P-6.4 Working Group on Fiber Optic Test Methods and Instrumentation.)

This FOTP forms a part of the latest revision of EIA Recommended Standard RS-455.

1. INTENT

1.1 This test is conducted to determine the suitability of fiber optic connectors and connector assemblies to withstand shocks such as those expected from rough handling, transportation, and military operations.

1.2 Typical Failure Modes

Typical failure modes for this test include:

(a) Cracking, breaking or loosening of parts.

(b) Optical discontinuity.

(c) Changes in optical transmission during and after shock.

2. TEST EQUIPMENT

2.1 Shock Machine

The shock machine utilized shall be capable of producing the specified input shock pulse as shown in Figures 1 or 2, as applicable. The shock machine may be of the free fall, resilient rebound, nonresilient, hydraulic, compressed gas, or other activating types.

2.1.1 Shock Machine Calibration

The actual test item or a rigid dummy mass may be used to calibrate the shock machine. When a dummy mass is used, it shall have the same center of gravity and the same mass as that of the test item, and shall be installed on the shock machine in a manner similar to that of the test item. The shock machine shall then be calibrated for conformance with the specified waveform.

2.1.1 Shock Machine Calibration (continued)

The shock machine shall be considered as calibrated when two consecutive shock applications to the calibration load produce waveforms which fall within the tolerance envelope given in Figures 1 or 2, as applicable for the Test Condition Letter specified. The calibration load shall then be removed and, without changing the specimen mounting configuration or shock machine control settings, the shock test shall be performed on the actual test item.

NOTE: It is not implied that the waveform generated with the actual test item installed will be identical to that produced with the calibration load installed. However, the test item waveform will be considered as satisfactory if the waveform generated with the calibration load is satisfactory.

2.2 Instrumentation

In order to meet the tolerance requirements of the test procedure, the instrumentation used to measure the input shock shall have the characteristics specified in the following:

2.2.1 Frequency Response

The frequency response of the complete measuring system, including the transducer through the readout instrument, shall be as specified in Figure 3.

2.2.1.1 Frequency Response Measurement of the Complete Instrumentation

The transducer-amplifier-recording system can be calibrated by subjecting the transducer to sinusoidal vibrations of known frequencies and amplitudes for the required ranges so that the overall sensitivity curve can be obtained. The sensitivity curve, normalized to be equal to unity at 100 Hz, shall then fall within the limits given in Figure 3.

2.2.1.2 Frequency Response Measurement of Auxiliary Equipment

If calibration factors given for the accelerometer are such that, when used with the associated equipment, it will not affect the overall frequency response, then the frequency response of the amplifier-recording system may be determined. This shall be determined in the following manner:

(a) Disconnect the accelerometer from the input terminals of its amplifier.

(b) Connect a signal voltage source to these terminals.

(c) The impedance of the signal voltage source as seen by the amplifier shall be made as the impedance of the accelerometer and associated circuitry as seen by the amplifier.

(d) With the frequency of the signal voltage set at 100 Hz, adjust the magnitude of the voltage to be equal to the product of the accelerator sensitivity and the acceleration magnitude expected during test conditions.

(e) Adjust the system gain to a convenient value.

(f) Maintain a constant input voltage and sweep the input frequency over the range from 1.0 to 9,000 Hz, or 4 to 25,000 Hz, as applicable, depending on duration of pulse. The frequency response in terms of dB shall be within the limits given in Figure 3.

2.2.2 Transducer

The fundamental resonant frequency of the accelerometer shall be greater than 30,000 Hz, when the accelerometer is employed as the shock sensor.

2.2.3 Transducer Calibration

The accuracy of the calibration method shall be at least ± 5% over the frequency range of 2 to 5,000 Hz. The amplitude of the transducer being calibrated shall also be ± 5% over the frequency range of 4 to 5,000 Hz.

2.2.4 Linearity

The signal level of the system shall be chosen so that the acceleration pulse operates over the linear portion of the system.

2.2.5 Transducer Mounting

When conformance to paragraph 2.3 is required, the monitoring transducer shall be rigidly secured and located as near as possible to an attachment point of the specimen, but not on the specimen itself.

2.3 Application of Shock Measuring Instrumentation

Shock measuring instrumentation shall be utilized to determine that the correct input shock pulse is applied to the test specimen. This is particularly important where a multi-specimen test is made. Generally, the shock pulse shall be monitored whenever there is a change in the test setup, such as a different test fixture, different component (change in physical characteristics), different weight, different shock pulse (change in pulse shape, intensity, or duration) or different shock machine characteristics. It is not mandatory that each individual shock be monitored, provided that the repeatability of the shock application as specified in paragraph 2.1.1 has been established.

2.4 Shock Pulses

Two types of shock pulses, a half-sine shock pulse and a sawtooth shock pulse, are specified. The pulse shape and tolerance are shown in Figures 1 and 2, respectively. For single degree of freedom systems, a sawtooth shock pulse can be assumed to have a damage potential at least as great as that of a half-sine pulse of the shock spectrum of the sawtooth pulse is everywhere at least as great as that of the half-sine pulse. This condition will exist for two such pulses of the same duration, if over most of the spectrum the acceleration peak value of the sawtooth pulse is 1.4 times the acceleration peak value of the half-sine pulse.

2.4.1 Half-Sine Shock Pulse

The half-sine shock pulse shall be as indicated in Figure 1. The velocity change of the pulse shall be within $\pm$ 10% of the velocity change of the desired shock pulse. The velocity change may be determined either by direct measurement, indirectly, or by integrating (graphically or electrically) the area (faired acceleration pulse may be used for the graphical representation) under the measured acceleration pulse. For half-sine acceleration pulses of less than 3 ms duration, the following tolerances shall apply: The faired maximum value of the measured pulse shall be within $\pm$ 20% of the specified ideal pulse amplitude, its duration shall be within $\pm$ 15% pf the specified ideal pulse duration, and the velocity-change associated with the measured pulse shall be within $\pm$ 10% of $V_i = 2AD/\pi$. See Figure 1. The measured pulse will then be considered a nominal half-sine pulse with a nominal amplitude and duration equal to respective values of the corresponding ideal half-sine pulse. The duration of the measured pulse shall be taken as $D_m = D(.1A)/.94$; where D(.1A) is the time between points at .1A for the faired measured acceleration pulse.

2.4.2 The Ideal Half-Sine Pulse

An ideal half-sine acceleration pulse is given by the solid curve (see Figure 1). The measured acceleration pulse shall lie within the boundaries given by the broken lines. In addition, the actual velocity-change of the shock shall be within 10% of the ideal velocity-change. The actual velocity-change can be determined by direct measurements, or from the area under the measured acceleration curve. The ideal velocity-change is equal to $V_i = 2AD/\pi$; where A is the acceleration amplitude and D is the pulse duration of the ideal pulse.

2.4.3 Sawtooth Shock Pulse

The sawtooth pulse shall be as indicated in Figure 2. The velocity-change of the faired measured pulse shall be within $\pm$ 10% of the velocity-change of the ideal pulse.

2.4.4 The Ideal Terminal-Peak Sawtooth

An ideal terminal-peak sawtooth acceleration pulse is given by the solid line (see Figure 2). The measured acceleration pulse shall be within the boundaries given by the broken line. In addition, the actual velocity-change of the shock pulse shall be within 10% of the ideal value. The actual velocity-change can be determined from direct measurements or from the area under the measured acceleration curve. The ideal velocity-change is equal to $V_i = PD/2$, where P is the peak value of acceleration, and D is the pulse duration.

3. TEST SPECIMEN

The test specimen (mated or unmated) shall be mounted as specified. Whenever possible, the test load shall be distributed uniformly on the test platform in order to minimize the effects of unbalanced loads.

4. TEST PROCEDURE

4.1 Basic Design Test

Three shocks in each direction shall be applied along the three mutually perpendicular axes of the test specimen (18 shocks). Unless otherwise specified, if the test specimen is normally mounted on vibration isolators, the isolators shall be functional during the test. The specified test pulse (half-sine or sawtooth pulse) shall be in accordance with Figures 1 and 2 respectively, and shall have a duration and peak value in accordance with one of the test conditions shown in Table I.

TABLE I

TEST CONDITION VALUES

Test Condition	Peak Value (g's)	Normal Duration (d) (ms)	Waveform	Velocity Change (V) m/s (ft/s)
A	50	11	Half-sine	3.44 (11.3)
B	75	6	Half-sine	2.80 (9.6)
C	100	6	Half-sine	3.75 (12.3)
D[1]	300	3	Half-sine	5.61 (18.4)
E	50	11	Sawtooth	2.68 (8.8)
F	75	6	Sawtooth	2.19 (7.2)
G	100	6	Sawtooth	2.96 (9.7)
H	30	11	Half-sine	2.07 (6.8)
I	30	11	Sawtooth	1.62 (5.3)

1/ For test condition D, where the weight of multi-specimen and fixtures exceed 68 kg (or 150 lb), there is a question as to whether the shock pulse is properly transmitted to all specimens. Due consideration shall be given to the design of the test fixture to assure the proper shock input to each specimen.

4.2 Measurements

The measurements made before, during, or after the test shall be as specified. Measurement for change in optical transmittance shall be made in accordance with RS-455-20, FOTP-20, "Measurement of Change in Optical Transmittance". Optical discontinuity may be verified by the method described in RS-455-32, FOTP-32, "Fiber Optic Circuit Discontinuities".

5. DOCUMENTATION

5.1 The test data sheets shall contain the following information:

5.1.1 Title of test, date and names of personnel.

5.1.2 Sample description - include fixture, if applicable.

5.1.3 Test equipment used and date of latest calibration.

5.1.4 Test condition letter (see Table I).

5.1.5 Photographs, values and observations necessary for proof of conformance.

6. SUMMARY

6.1 The following details shall be specified in the Detail Specifications:

6.1.1 Mounting methods and accessories (see Section 3.).

6.1.2 Test specimens (mated or unmated) (see Section 3.).

6.1.3 Test condition letter (see Table I).

6.1.4 Measurements before, during and after the test (see paragraph 4.2).

6.1.5 Treatment of vibration isolators, when present, if other than specified in paragraph 4.1.

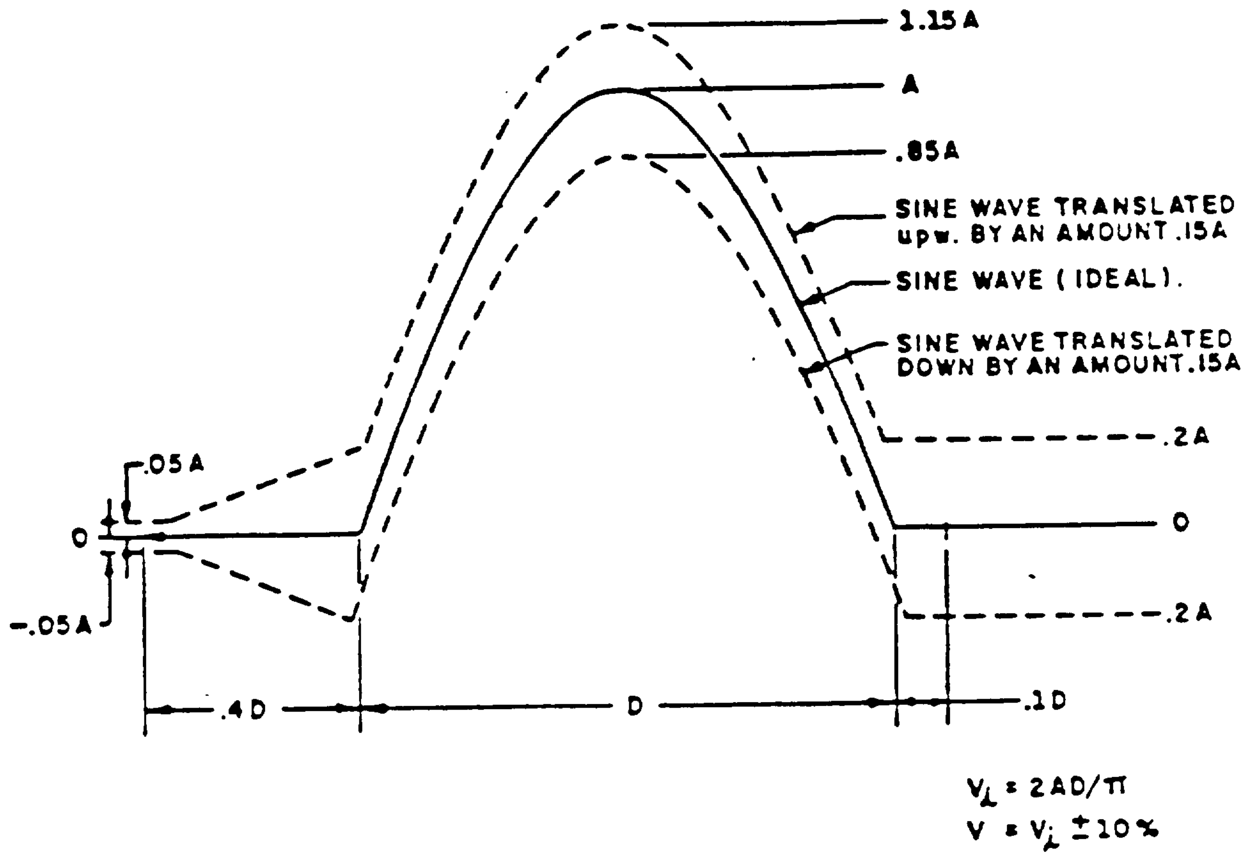


FIGURE 1

TOLERANCES FOR HALF SINE SHOCK PULSE

NOTE:
The oscillogram should include a time about 3D long with the pulse located approximately in the center. The integration to determine the velocity change should extend from .4D before the pulse to .1D beyond the pulse. The acceleration amplitude of the ideal half sine pulse is A and its duration is D. Any measured acceleration pulse which can be contained between the broken line boundaries is a nominal half sine pulse of nominal amplitude A and nominal duration A. The velocity change associated with the measured acceleration pulse is V.

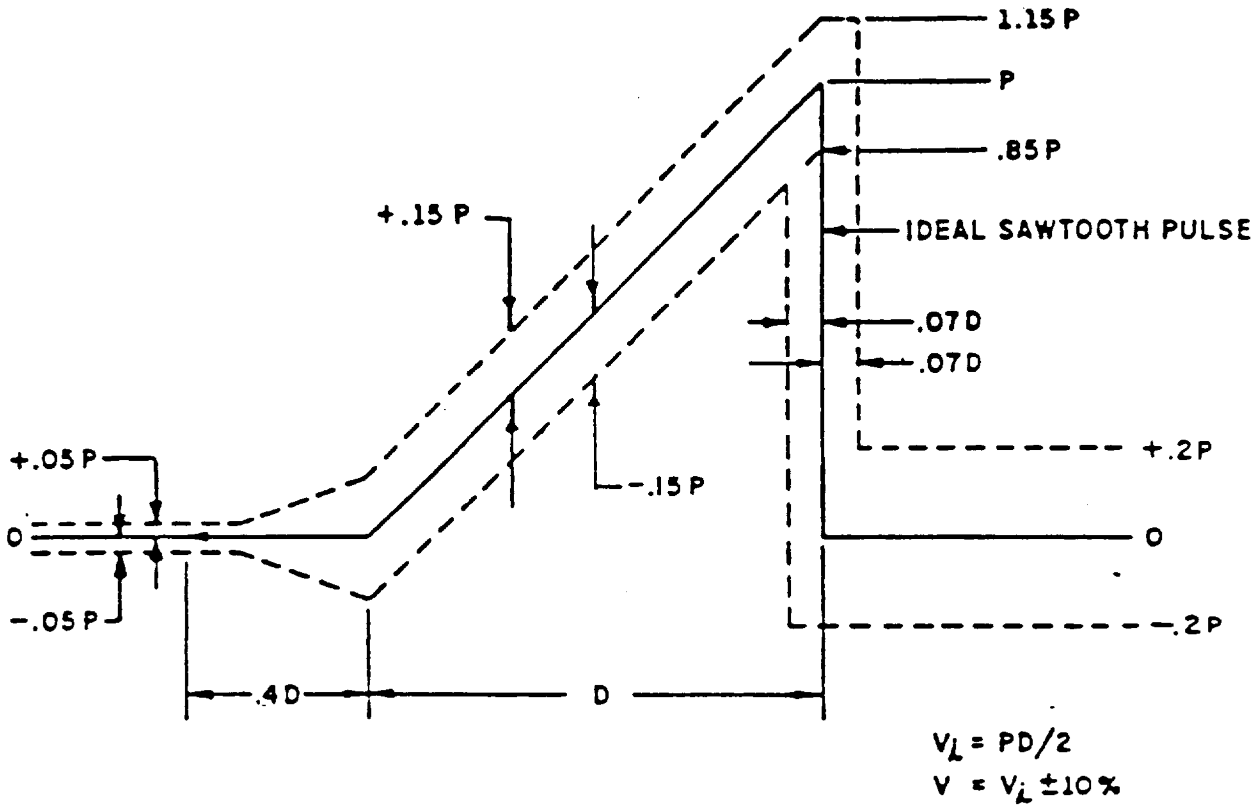
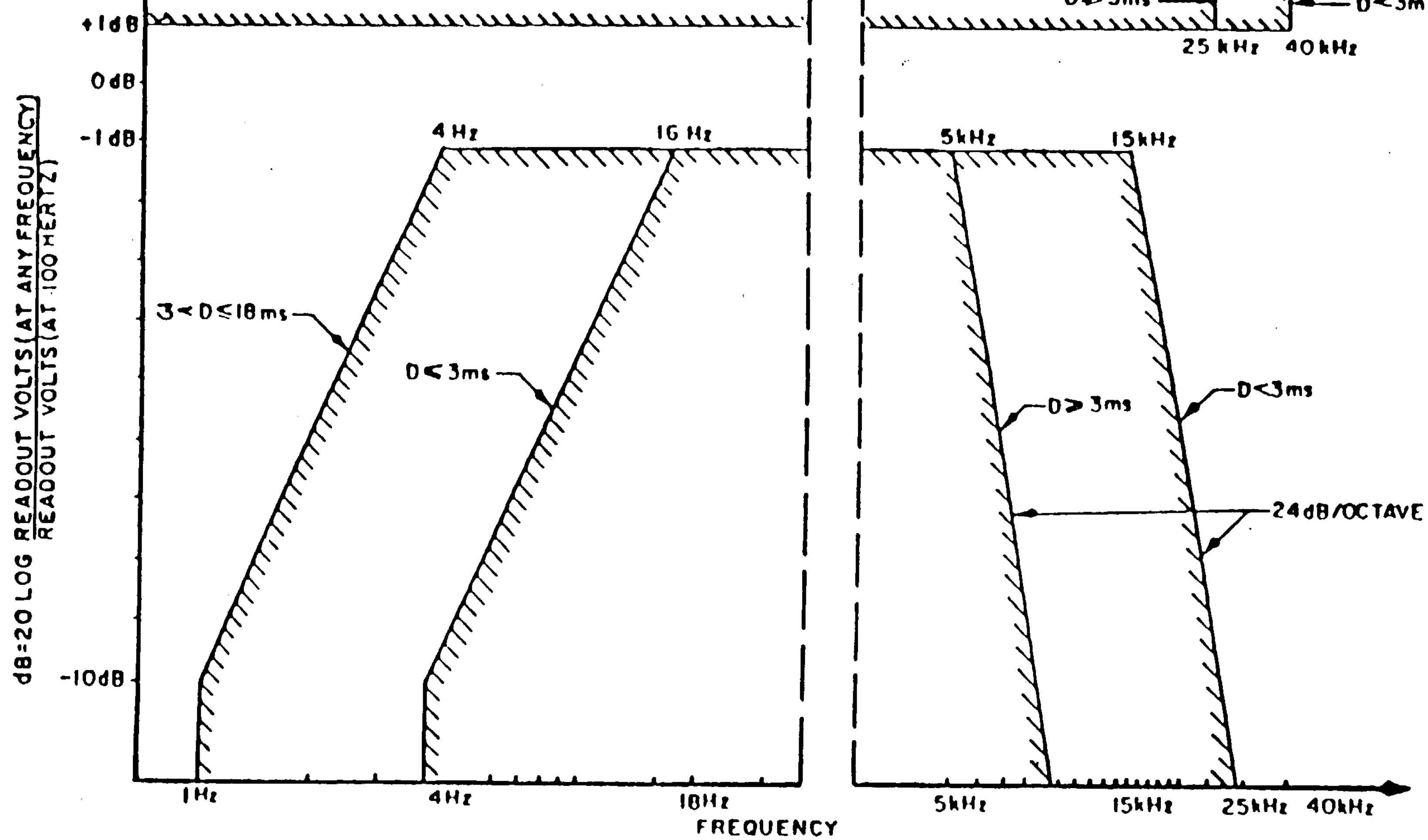


FIGURE 2

TOLERANCES FOR TERMINAL-PEAK SAWTOOTH SHOCK PULSE

NOTE:
The oscillogram should include a time about 3D long with the pulse approximately in the center. The integration to determine the velocity change should extend from .4D before the pulse to .1D beyond the pulse. The peak acceleration magnitude of the sawtooth pulse is P and its duration is D. Any measured acceleration pulse which can be contained between the broken line boundaries is a nominal terminal-peak sawtooth pulse of nominal peak value, P, and nominal duration, D. The velocity change associated with the measured acceleration pulse is V.



Duration of pulse (ms)	Low-frequency cut-off (Hz)		High-frequency cut-off (kHz)	Frequency beyond which the response may rise above +1dB (kHz)
	-1dB	-10dB	-1dB	
<3	16	4	15	40
3	16	4	5	25
>3	4	1	5	25

Figure 3 Tolerance Limits for Measuring System Frequency Response

Appendix G

Radiation Testing

FOTP-49

PROCEDURE FOR MEASURING GAMMA IRRADIATION EFFECTS IN OPTICAL FIBERS AND OPTICAL CABLES

(From EIA Standards Proposal No. 1897-A, formulated under the cognizance of the EIA/TIA FO-6.6 Subcommittee on Optical Fiber and Materials.)

This FOTP is part of the series of test procedures included within Recommended Standard EIA/TIA-455.

NOTE: This FOTP was originally published in RS-455-49 as FOTP-49.

1.0 INTENT

This test procedure outlines a method for measuring the steady state response of optical fibers and optical cables exposed to gamma radiation. It can be employed to determine the level of radiation-induced attenuation produced in single-mode or multimode optical fibers, in either cabled or uncabled form, due to exposure to gamma radiation. This test is not a materials test for the non-optical material components of a fiber optic cable. If degradation of cable materials exposed to irradiation is to be studied, other test methods will be required.

1.1 Background

The attenuation of cabled and uncabled optical fibers generally increases when exposed to gamma radiation. This is primarily due to the trapping of radiolytic electrons and holes at defect sites in the glass (i.e., the formation of color centers). This test procedure focuses on two regimes of interest: the low dose rate regime for estimating the effect of environmental background radiation, and the high dose rate regime for estimating the effect of adverse nuclear environments. The testing of the effects of environmental background radiation is achieved with a two-point attenuation measurement approach similar to FOTP-46 (EIA-455-46), "Spectral Attenuation Measurement for Long-Length, Graded-Index Optical Fibers," or FOTP-78 (EIA-455-78), "Spectral Attenuation Cutback Measurement for Single-Mode Optical Fibers." The effects of adverse nuclear environments are tested by monitoring the power before, during and after exposure of the test sample to gamma radiation. The depopulation of color centers by light (photobleaching) or by heat causes recovery (lessening of radiation-induced attenuation). Recovery may occur over a wide range of time scales ranging from 10^{-2} second to 10^{+4} seconds. This complicates the characterization of radiation-induced attenuation since the attenuation depends on many variables including the temperature of the test environment, the configuration of the sample, the total dose and the dose rate applied to the test sample and the light level used to measure it.

1.2 Caution

Carefully selected trained personnel must be used to perform this test. It can be extremely hazardous to test personnel if it is improperly performed.

2.0 REFERENCED DOCUMENTS

Test or inspection requirements may include, but are not limited to, the following references:

FOTP-46 (EIA-455-46) "Spectral Attenuation Measurement for Long-Length, Graded-Index Optical Fibers"

FOTP-50 (EIA-455-50) "Light Launch Conditions for Long-Length Graded-Index Optical Fiber Spectral Attenuation Measurements"

FOTP-57 (EIA-455-57) "Optical Fiber End Preparation and Examination"

FOTP-78 (EIA-455-78) "Spectral Attenuation Cutbak Measurement for Single-Mode Optical Fibers"

FOTP-80 (EIA-455-80) "Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power"

3.0 TEST EQUIPMENT — (See Figures 1 & 2)

3.1 Radiation Source

3.1.1 Testing of Environmental Background Radiation

A cobalt-60 or equivalent ionizing source shall be used to deliver gamma radiation at a low dose rate of ≤ 20 Rads/h (see Figure 1).

3.1.2 Testing of Adverse Nuclear Environments

A cobalt-60 or equivalent ionizing source(s) shall be used to deliver gamma radiation at a dose rate ranging from 5 Rads/s to 250 Rads/s (see Figure 2).

3.2 Light Source

A light source such as a tungsten-halogen lamp or set of lasers or LEDs shall be used to produce radiant energy at wavelengths of 850 nm, 1300 nm, and 1550 nm or at wavelengths as specified in the Detail Specification. (Lasers shall not be used to test multimode fibers in military applications.) The light source shall be stable in intensity over a time period sufficient to perform the measurement. The power coupled from the source into the test sample shall be ≤ -30 dBm (1.0 µwatt) or as specified in the Detail Specification. The light source shall be modulated with a pulsed signal at a 50% duty cycle.
Note: If a source that couples more than 1.0 µwatt is used, photobleaching may occur.

3.3 Optical Filters/Monochromators

Unless otherwise specified, wavelengths of 850 ± 20 nm, 1300 ± 20 nm, and 1550 ± 20 nm shall be obtained by filtering the light source with a set of optical filters or a monochromator. The 3 dB optical bandwidth of the filters shall be less than or equal to 25 nm.

3.4 Cladding Mode Stripper

When necessary, a device that extracts cladding modes shall be employed at the input end of the test sample. If the fiber coating materials are designed to strip cladding modes, a cladding mode stripper is not required.

3.5 Fiber Support and Positioning Apparatus

A means of stably supporting the input end of the test sample such as a vacuum chuck, shall be arranged. This support shall be mounted on a positioning device so that the end of the test sample can be repeatedly positioned in the input beam.

3.6 Optical Splitter — (See Figure 2)

An optical splitter or fiber optic coupler shall divert a small portion of the input light to a reference detector. The reference path shall be used to monitor system fluctuations for the duration of the test.

3.7 Input Launch Simulator

3.7.1 Class Ia Fibers (Graded Index Multimode Fiber)

An equilibrium mode simulator shall be used to attenuate higher order propagating modes and to establish a steady-state mode condition near the input end of the fiber. Refer to FOTP-50 (EIA-455-50), "Light Launch Conditions for Long-Length Graded-Index Optical Fiber Spectral Attenuation Measurements," for instructions on how to establish proper launch conditions for Class Ia graded index multimode fibers.

3.7.2 Class IV Fibers — (Single-Mode Fiber)

An optical lens system or fiber pigtail may be employed to excite the test fiber. The power coupled into the test sample must be stable for the duration of the test. If an optical lens system is used, a method of making the positioning of the fiber less sensitive is to overfill the fiber end spatially and angularly. If a pigtail is used, it may be necessary to use index matching material to eliminate interference effects. A high order mode filter shall be employed to remove high order propagating modes in the wavelength range greater than or equal to the cutoff wavelength of the test fiber. The test condition specified in Section 4.1 of FOTP-80 (EIA-455-80), "Cutoff Wavelength of Uncabled Single-Mode Fiber by Transmitted Power," satisfies this requirement.

3.7.3 Classes Ib and Ic Fibers (Quasi-graded and Step Index Fibers)

Launch conditions shall be created as specified in the Detail Specification.

3.8 Detector — Signal Detection Electronics

An optical detector which is linear and stable over the range of intensities that are encountered shall be used. A typical system might include a photovoltaic mode photodiode amplified by a current input preamplifier, with synchronous detection by a lock-in amplifier.

3.9 Optical Power Meter

An optical power meter shall be used to determine that the power coupled from the optical source into the test sample is less than or equal to 1.0 μwatt or the level specified in the Detail Specification.

3.10 **Radiation Dosimeter**

Thermoluminescent LiF or CaF Crystal Detectors (TLDs) shall be used to measure the total radiation dose received by the specimen fiber.

3.11 **Temperature Controlled Container**

Unless otherwise specified, the temperature controlled container shall have the capability of maintaining the specified temperatures to within ± 2°C.

3.12 **Test Reel**

The test reel shall not act as a shield or sink for the radiation used in this test.

4.0 TEST SAMPLE

4.1 **Specimens**

4.1.1 Fiber Specimen

The test specimen shall be a representative sample of the fiber specified in the Detail Specification.

4.1.2 Cable Specimen

The test specimen shall be a representative sample of the cable described in the Detail Specification and shall contain at least one of the specified fibers.

4.2 **Specimen for Environmental Background Radiation Test**

Unless otherwise specified in the Detail Specification, the length of the test sample shall be 3 km ± 20 m (9850 ± 65 ft). [Where reactor constraints dictate smaller lengths, the length of the test sample may be 1100 m ± 20 m (3608 ± 65 ft).] A minimum length at the ends of the test sample [typically ≤ 5 meters (16 ft)] shall reside outside of the test chamber and be used to connect the optical source to the detector. The irradiated length of the test sample shall be reported.

4.3 **Specimen for Testing Adverse Nuclear Environments**

Unless otherwise specified in the Detail Specification, the length of the test sample shall be 250 meters ± 1 m (820 ± 3 ft). (When test conditions require a high total dose and dose rate, per Table I, a shorter test sample length may be necessary.) A minimum length at the ends of the test sample [typically ≤ 5 meters (16 ft)] shall reside outside the test chamber and be used to connect the optical source to the detector. The irradiated length of the test sample shall be reported.

4.4 **Test Reel**

The test sample shall be spooled onto a reel with a drum diameter that is specified in the Detail Specification. Allowance shall be made for the unspooling of a measured length of the test sample from each end of the reel to allow for attachment to the optical measurement equipment.

4.5 **Ambient Light Shielding**

The test sample shall be shielded from ambient light to prevent external photobleaching.

5.0 TEST PROCEDURE

5.1 Calibration of Radiation Source

Calibration of the radiation source for dose uniformity and level shall be made prior to the test sample being set up in the chamber. Four TLDs shall be placed in the area of exposure and the center of the TLDs shall be placed where the axis of the test reel will be placed. (Four TLDs are used to get a representative average value.) A dose equal to the actual test dose shall be used to calibrate the system. To maintain the highest possible accuracy in measuring the test dose, the TLDs shall not be used more than once.

5.2 Fiber End Preparation

The test sample shall be prepared such that its endfaces are smooth and perpendicular to the fiber axis, in accordance with FOTP-57 (EIA-455-57), "Optical Fiber End Preparation and Examination."

5.3 Environmental Background Radiation Test

The procedures for measuring the attenuation (2 point loss measurement) of the test sample before and after exposure to the gamma radiation source are described below.

5.3.1 The reel of fiber or cable to be tested shall be placed in the test set-up in accordance with Figure 1.

5.3.2 The input end of the fiber shall be placed in a positioning device and aligned. The output end shall be positioned so that all light exiting the fiber impinges on the active surface of the detector.

5.3.3 The test sample shall be preconditioned in the temperature chamber at 25 ± 5°C for 1 hour prior to testing, or at the test temperature for a preconditioned time as specified in the Detail Specification.

5.3.4 A two-point attenuation measurement of the test sample shall be performed, at the specified test wavelengths, in accordance with the methods of FOTP-46, (for Class Ia fibers) or in accordance with the methods of FOTP-78, (for Class IV fibers). The Attenuation A_1, of the fiber prior to exposure to the gamma radiation source shall be recorded.

5.3.5 The power at the input end of the test sample (point A in Figure 1) shall be measured with a calibrated power meter. If necessary, the source level shall be adjusted so that the power at point A is less than 1.0 µwatt or as specified in the Detail Specification.

5.3.6 The test sample ends shall be prepared in accordance with Section 5.2 and aligned in the test set in accordance with Section 5.3.2.

5.3.7 With the radiation source off, the input end of the test sample shall be positioned to obtain maximum optical power at the detector. Once set, the input launch conditions shall not be changed during the gamma irradiation portion of the test.

5.3.8 Prior to irradiation, the output power shall be measured at all test wavelengths at the specified test temperature.

5.0 TEST PROCEDURE

5.1 Calibration of Radiation Source

Calibration of the radiation source for dose uniformity and level shall be made prior to the test sample being set up in the chamber. Four TLDs shall be placed in the area of exposure and the center of the TLDs shall be placed where the axis of the test reel will be placed. (Four TLDs are used to get a representative average value.) A dose equal to the actual test dose shall be used to calibrate the system. To maintain the highest possible accuracy in measuring the test dose, the TLDs shall not be used more than once.

5.2 Fiber End Preparation

The test sample shall be prepared such that its endfaces are smooth and perpendicular to the fiber axis, in accordance with FOTP-57 (EIA-455-57), "Optical Fiber End Preparation and Examination."

5.3 Environmental Background Radiation Test

The procedures for measuring the attenuation (2 point loss measurement) of the test sample before and after exposure to the gamma radiation source are described below.

5.3.1 The reel of fiber or cable to be tested shall be placed in the test set-up in accordance with Figure 1.

5.3.2 The input end of the fiber shall be placed in a positioning device and aligned. The output end shall be positioned so that all light exiting the fiber impinges on the active surface of the detector.

5.3.3 The test sample shall be preconditioned in the temperature chamber at 25 ± 5°C for 1 hour prior to testing, or at the test temperature for a preconditioned time as specified in the Detail Specification.

5.3.4 A two-point attenuation measurement of the test sample shall be performed, at the specified test wavelengths, in accordance with the methods of FOTP-46, (for Class Ia fibers) or in accordance with the methods of FOTP-78, (for Class IV fibers). The Attenuation A_1, of the fiber prior to exposure to the gamma radiation source shall be recorded.

5.3.5 The power at the input end of the test sample (point A in Figure 1) shall be measured with a calibrated power meter. If necessary, the source level shall be adjusted so that the power at point A is less than 1.0 μwatt or as specified in the Detail Specification.

5.3.6 The test sample ends shall be prepared in accordance with Section 5.2 and aligned in the test set in accordance with Section 5.3.2.

5.3.7 With the radiation source off, the input end of the test sample shall be positioned to obtain maximum optical power at the detector. Once set, the input launch conditions shall not be changed during the gamma irradiation portion of the test.

5.3.8 Prior to irradiation, the output power shall be measured at all test wavelengths at the specified test temperature.

5.3.9 A chart recorder or continuous measurement device shall be connected to the detection system so that a continuous power measurement can be made. The measurement equipment shall be set up such that the detection signal does not exceed the limits of the equipment.

5.3.10 Environmental background radiation effects, due to exposure to gamma radiation, shall be determined by subjecting the test sample to dose rates of ≤ 20 Rads/h. The test sample shall be exposed to a minimum total dose of at least 100 rads.

5.3.11 The output power from the test sample shall be recorded for the duration of the gamma irradiation cycle.

5.3.12 Upon completion, and within 2 hours, of the irradiation process, a two-point attenuation measurement of the test sample shall be performed in accordance with Section 5.3.4. The attenuation, A_2, of the test sample after exposure to the gamma radiation source shall be recorded.

5.3.13 Repeat steps 5.3.1 through 5.3.12 for the required test temperatures and wavelengths. It will be necessary to use a new non-irradiated specimen for each temperature required.

5.4 Adverse Nuclear Environment Test

The procedures for measuring the power propagating in the test sample before, during and after exposure to the gamma radiation source are described below.

5.4.1 The ends of a short length of test sample (1 to 2 meters) shall be prepared according to Section 5.2.

5.4.2 The input end of the short test length shall be placed in the positioning device and aligned in the test set (Figure 2) to obtain maximum optical power as measured with a calibrated power meter. If necessary, the source level shall be adjusted, using neutral density filters, to obtain an optical power level at the output of the short length of test sample that is less than 1.0 µwatt or as specified in the Detail Specification.
Note: If a source that couples more than 1.0 µwatt is used, photobleaching may occur.

5.4.3 The test sample reel shall be placed in the test set-up in accordance with Figure 2.

5.4.4 The input end of the test sample shall be placed in a positioning device and aligned. The output end shall be positioned so that all light exiting the test sample impinges on the active surface of the detector.

5.4.5 The test sample shall be preconditioned in the temperature chamber at 25 ± 5°C for 1 hour prior to testing, or at the test temperature for a preconditioning time as specified in the Detail Specification.

5.4.6 With the radiation source off, the input end of the test sample shall be positioned to obtain maximum optical power at the detector. Once set, the input launch conditions shall not be changed during the gamma irradiation portion of the test.

5.4.7 Prior to irradiation, the output power shall be measured at all test wavelengths at the specified test temperature. The power from the reference detector shall also be measured at this time.

5.4.8 A chart recorder or continuous measurement device shall be connected to the detection system so that a continuous power measurement can be made. The measurement equipment shall be set up such that the detection signal does not exceed the limits of the equipment.

5.4.9 Adverse effects due to exposure to gamma radiation shall be determined by subjecting the test sample to at least one of the dose rates and total dose level combinations specified in Table I or as specified in the Detail Specification.

TABLE I

TOTAL DOSE/DOSE RATE COMBINATIONS

Total Dose, Rads (Si)	Dose Rate, Rads/s
3,000	5
10,000	50
100,000	200
1,000,000	200

Dose rate levels are only approximate levels since the radiation source characteristics change. A variation in dose rate as high as ± 50% can be expected between sources. The time required to turn the radiation source on or off shall be ≤ 10% of the total exposure time.

5.4.10 The output power from the test sample shall be recorded for the duration of the gamma irradiation cycle. The power shall also be recorded for at least 15 minutes after completion of the irradiation process or as specified in the Detail Specification. The power level of the reference detector shall also be recorded during the recovery time after completion of the irradiation process.

5.4.11 Repeat steps 5.4.2 through 5.4.10 for the required test temperatures and wavelengths. It will be necessary to use a new non-irradiated specimen for each temperature required.

6.0 CALCULATIONS

6.1 The change in optical attenuation Δ A (Environmental Background Radiation Test)

$$\Delta A = A_2 - A_1 \quad dB$$

A_1 is the attenuation of the test sample prior to exposure to gamma radiation

A_2 is the attenuation of the test sample after exposure to gamma radiation.

6.2 The change in optical transmittance shall be calculated for each wavelength by using the following formula: (Testing of Adverse Nuclear Environment)

$$A_o = -10 \log (P_o \;/\; P_B) \quad dB$$

$$A_{15} = -10 \log (P_{15} \;/\; P_B) \quad dB$$

where:

P_o is the power output of the test sample within 1 second after irradiation is discontinued unless otherwise specified.

P_{15} is the power output of the test sample 15 minutes after irradiation is discontinued unless otherwise specified.

P_B is the power output of the test sample before irradiation begins.

A_o is the change in optical transmittance of the test sample immediately after irradiation.

A_{15} is the change in optical transmittance of the test sample 15 minutes after irradiation.

6.3 The results of the reference measurements should be used to normalize the test results if significant system instability is noted.

$$A_{REF} = -10 \log (P_{E'} \;/\; P_{B'}) \quad dB$$

where:

$P_{E'}$ is the power measured by the reference detector anytime after irradiation begins.

$P_{B'}$ is the power measured by the reference detector before irradiation begins.

6.4 Normalized test results that account for system instability are calculated with the following formula:

$$A_{o_{NOR}} = A_o - A_{REF}$$

$$A_{15_{NOR}} = A_{15} - A_{REF}$$

7.0 REPORT

7.1 The following data shall be reported:

7.1.1 Date of Test

7.1.2 Title of Test

7.1.3 Length of test sample exposed to radiation.

7.1.4 Test Wavelengths

7.1.5 Test Temperatures

7.1.6 Test Reel Diameter

7.1.7 Total Dose and Dose Rate

7.1.8 Change in attenuation, ΔA (Environmental Background Radiation Test).

7.1.9 Change in optical transmittances, A_o and A_{15} (Adverse Nuclear Environment).

7.1.10 Characteristics of test sample such as fiber type, cable type, dimensions and composition.

7.1.11 Chart recording of test events.

7.2 The following test equipment information shall be reported whenever this FOTP is specified in a U.S. Military document or for any U.S. Military application; this information shall be available for inspection upon request for non-military applications.

7.2.1 Description of radiation source.

7.2.2 Description of dosimeters used.

7.2.3 Type of optical source, model number and manufacturer.

7.2.4 Description of optical filters or monochrometer.

7.2.5 Description of cladding mode stripper.

7.2.6 Description of input launch simulator and launch conditions used.

7.2.7 Type of optical splitter used.

7.2.8 Description of detection and recording apparatus.

7.2.9 Description of the characteristics of temperature chamber.

7.2.10 Date of latest calibration of test equipment.

7.2.11 Name or Identification Number of Personnel.

8.0 SPECIFYING INFORMATION

The following details shall be specified in the Detail Specification:

8.1 Type of test sample to be tested.

8.2 Test Reel Diameter

8.3 Test Temperature(s)

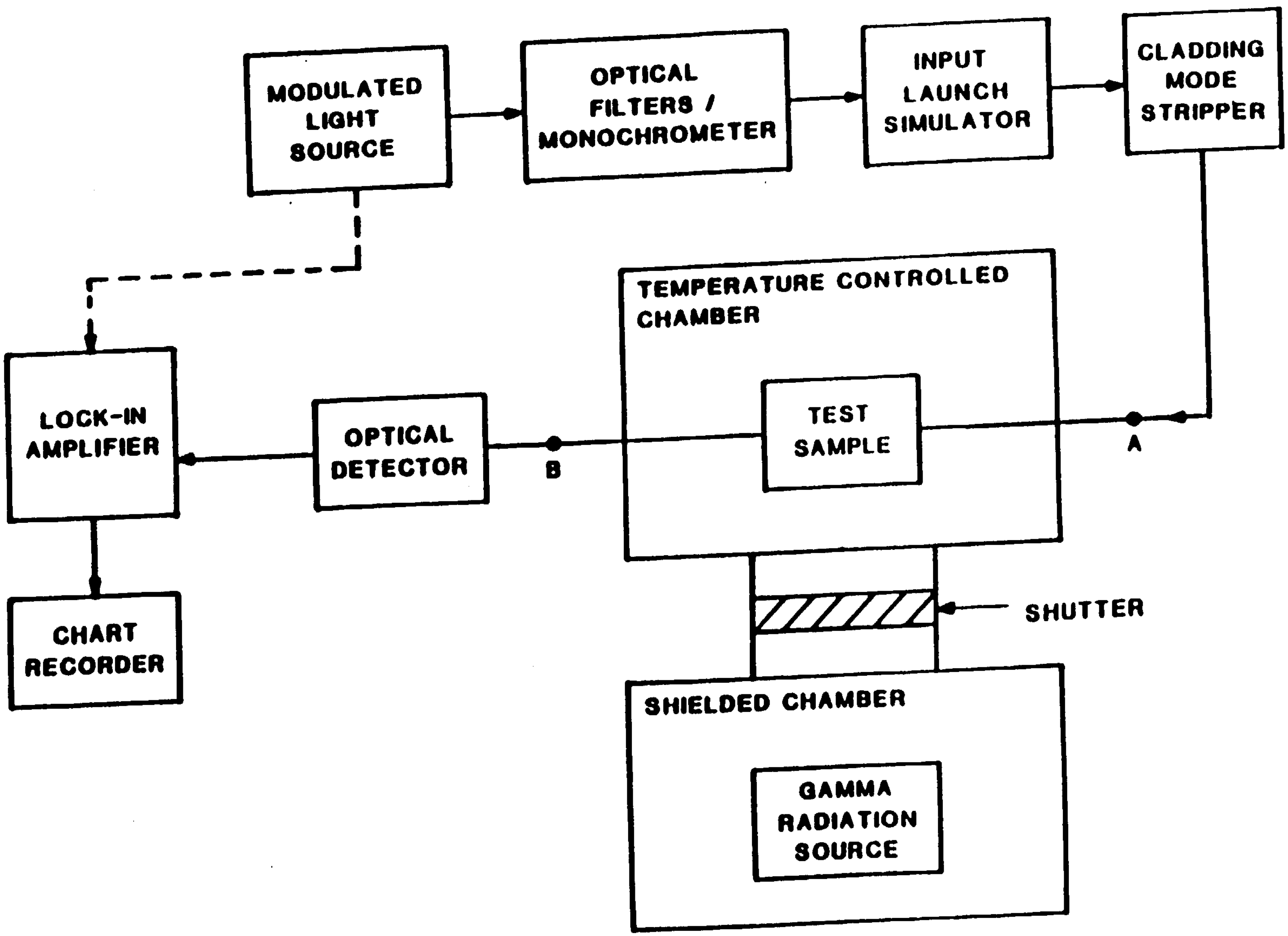
8.4 Failure or acceptance criteria.

8.5 Number of Samples

8.6 Test Wavelengths

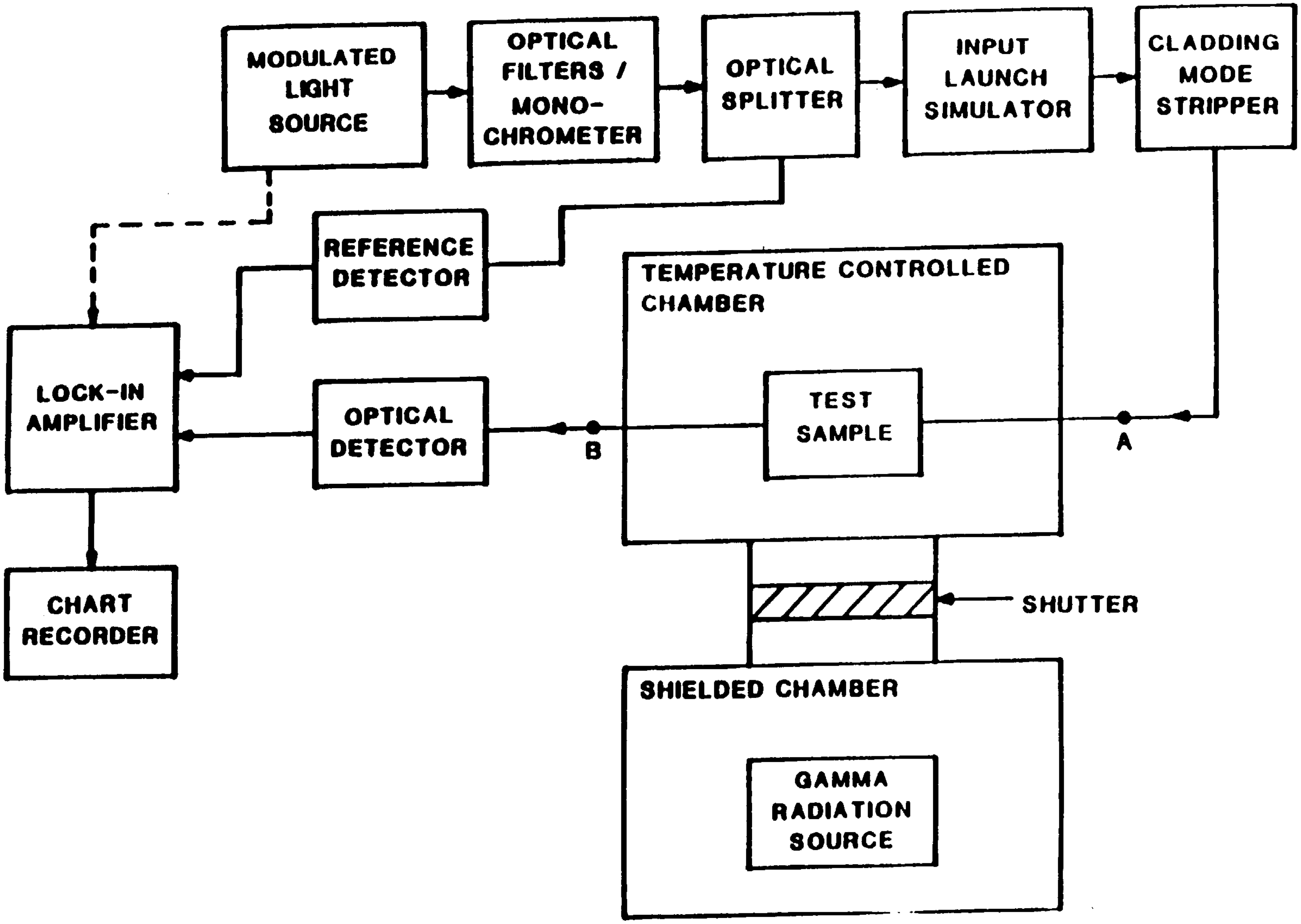
8.7 Total Dose and Dose Rate

8.8 Other Test Conditions



INSTRUMENTATION FOR ENVIRONMENTAL BACKGROUND RADIATION TESTING

FIGURE 1



INSTRUMENTATION FOR TESTING THE EFFECTS OF ADVERSE NUCLEAR ENVIRONMENTS

FIGURE 2

APPENDIX 4

Evaluation Test Data Sheets

TABLE OF CONTENTS

1 - 1.0 Scope

This appendix 1, to <u>Fiber Optic Feedthrough and Sealing Evaluation Test Report</u>, contains data sheets and test set-up information for the environmental, mechanical and optical testing conducted in this development effort. The sequence of tests is shown in para. 6.0 of the main body of the test report, LC-T-94-C027-TR.

1 - 2.0 Insertion Loss

Insertion loss was conducted as the feedthrough units were constructed in accordance with 2.2 of Appendix II. The test was conducted in accordance with EIA/TIA-455-34.

1 - 2.1 Set-up

The following data sheets show insertion loss levels for the feedthroughs later subjected to testing. Note that feedthroughs A, B, C, D were used in radiation testing and that feedthroughs C1, C2, C3, C4 were used for the other mechanical and environmental tests. Also note that as anticipated, losses were negligible for the Type I feedthroughs since the fibers were never cut in the construction of the feedthroughs. Type II feedthroughs exhibited losses of -0.5 to -0.7 dB, except gold-coated fibers had losses of 0.8 dB.

1 - 2.2 Data Sheets

Test set-up figures are followed by actual insertion loss data.

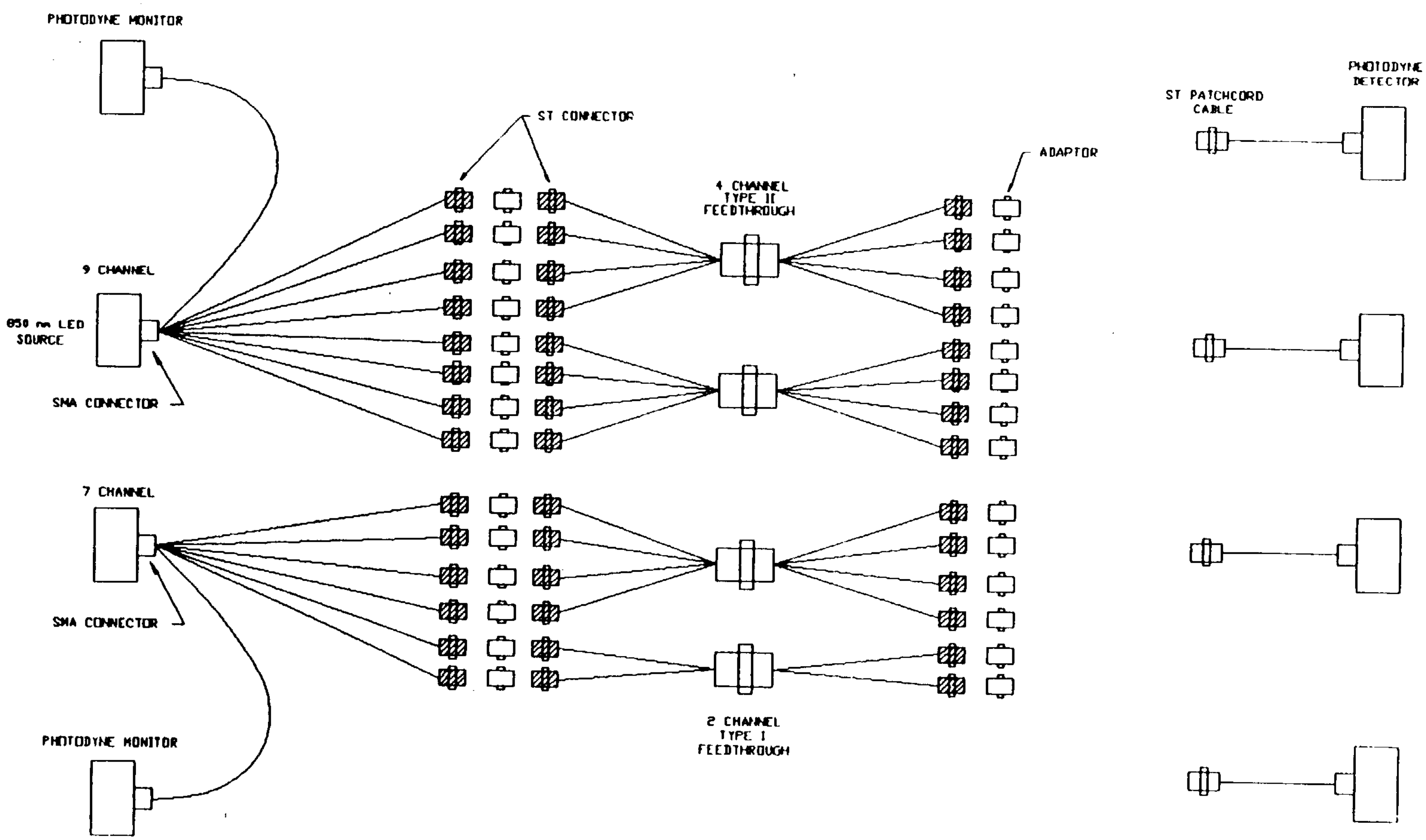


Figure 1 Optical Test Set-Up, Set A

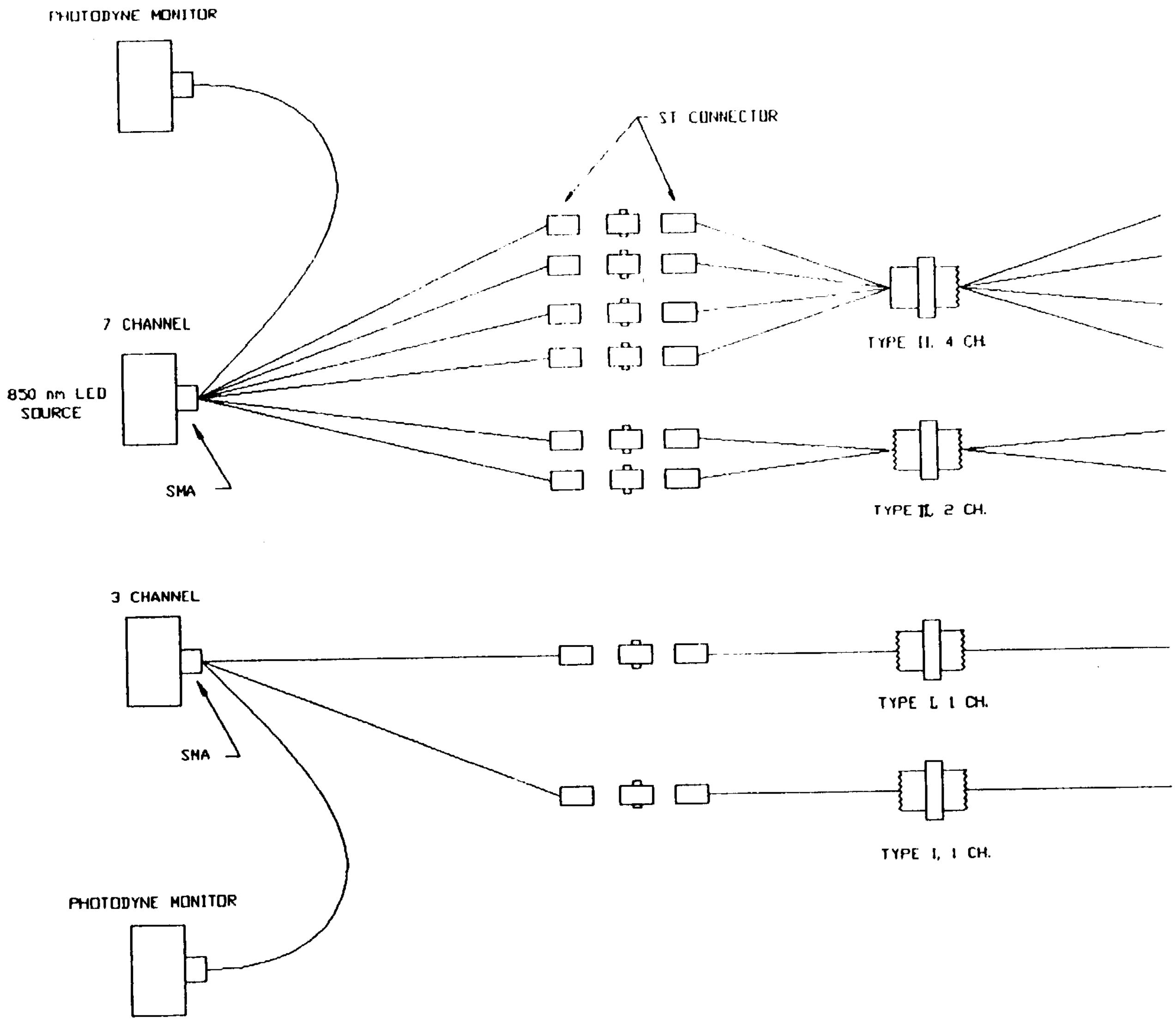


Figure 2 Optical Test Set-Up, Set B

ENGINEERING TEST LABORATORY

GENERAL DATA SHEET

TEST: OPTICAL INSERTION LOSS TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: C1:LC-100G-4-PSP-36
C2:LC-100G-4-ALHUGH-37
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: ROOM TEMPERATURE

PART NO. CO27FT
SAMPLE NO.
PARA NO.

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
C1A	-12.07	-11.24	-11.86	-0.62
C1B	-12.07	-12.79	-13.31	-0.52
C1C	-12.07	-11.91	-12.54	-0.63
C1D	-12.07	-11.80	-12.40	-0.60
C2A	-12.07	-11.12	-11.70	-0.58
C2B	-12.07	-12.33	-12.92	-0.59
C2C	-12.07	-11.52	-12.05	-0.53
C2D	-11.96	-12.00	-12.53	-0.53
C3A	-11.97	-14.30	-15.07	-0.77 **
C3B	-11.96	-12.17	-13.00	-0.83 **
C3C	-12.07	-13.15	-13.96	-0.81 **
C3D	-12.07	-13.40	-14.12	-0.72 **
C4A	-12.07	-12.86	-12.88	-0.02 ***
C4B	-11.96	-13.30	-13.31	-0.01 ***

* LIGHT SOURCE: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED FIBER WITH LARGE VARIATION FIBER O.D.
*** TYPE I FEEDTHROUGH WITH CONTINUOUS FIBER (WITHOUT CONNECTOR LOSS)

TEST BY: TEUNIS VISSER DATE: JANUARY 4, 1994

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY

GENERAL DATA SHEET

TEST: OPTICAL INSERTION LOSS TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33
SPECIFICATION: ROOM TEMPERATURE

PART NO. CO27FT
SAMPLE NO.
PARA NO.

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-11.3	-11.85	-11.86	-0.01 ***
B-A		-11.80	-11.82	-0.02 ***
C-A		-11.10	-11.90	-0.80 **
D-A		-10.60	-11.18	-0.58
D-B		-11.14	-11.78	-0.64
D-C		-9.10	-9.72	-0.62
D-D		-10.89	-11.56	-0.67

* LIGHT SOURCE: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED FIBER WITH LARGE VARIATION FIBER O.D.
*** TYPE I FEEDTHROUGH WITH CONTINUOUS FIBER (WITHOUT CONNECTOR LOSS)

TEST BY: TEUNIS VISSER DATE: JANUARY 20, 1994

ENGINEERING ____________ DATE:

1 - 3.0 Initial Leak Rate

Feedthroughs were tested for hermeticity by subjecting them to a pressure differential exposure of 10^{-11} cc/sec helium leak rate.

1 - 3.1 Data Sheets

Leak rate testing was performed by Helium Leak Testing, Inc. of Northridge, CA. Tests were conducted after each of the environmental and mechanical tests, and the leak rate test was always passed.

1 - 4.0 Thermal Shock

The thermal shock test was conducted per the test plan, Appendix II of this report, para. 2.4 and as reported in Appendix III, NTS test report. Thermal shock was conducted after salt spray, vibration and shock.

1 - 4.1 Set-up

Feedthrough test units C1, C2, C3, C4 per Table 1 were subjected to thermal cycling. The test units were subjected to the low temperature of -320°F (-196°C) for 30 minutes with a transition time of 5 minutes maximum for moving to the high temperature chamber. Soak time at high temperature of +392°F (+200°C) was 30 minutes. This constituted one complete cycle. Five complete cycles were conducted on each specimen.

Change in optical transmittance was monitored before, during and after the test to indicate optical performance influence by the exposure to the varied thermal conditions. This was done in accordance with EIA/TIA-455-20 "Measurement of Change in Optical Transmittance." Optical signalling was at 850 nanometer during exposure of feedthroughs C1, C2, C3, C4.

1 - 4.2 Data Sheets

Data Sheets follow for pre-test, 5 cycles, and post test optical measurements.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ________
C2:LC-100G-4-ALHUGH-37 PARA NO.____________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: PRE-TEST (ROOM TEMP)

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) PRE-MEASUREMENT BEFORE 5 CYCLES(ROOM TEMPERATURE)		
C1A	-12.11	-11.24		
C1B		-13.25		
C1C		-12.51		
C1D		-12.38		
C2A		-11.65		
C2B		-12.89		
C2C		-11.98		
C2D		-12.14		
C3A		**		
C3B		**		
C3C		**		
C3D		**		
C4A		-12.71		
C4B		-13.22		

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ________
C2:LC-100G-4-ALHUGH-37 PARA NO. ________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: 1ST CYCLE

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) TEMP @-320F 30 MIN.	MEASUREMENT (dBm) TEMP @+396F 30 MIN.	LOW TEMP DEVIATION FROM INITIAL	HIGH TE DEVIATI FROM INITIAL
C1A	-12.11	-11.30	-11.34	-0.06	-0.10
C1B		-13.28	-13.30	-0.03	-0.05
C1C		-12.50	-12.54	0.01	-0.03
C1D		-12.43	-12.40	-0.05	-0.02
C2A		-11.66	-11.74	-0.01	-0.09
C2B		-12.91	-12.94	-0.02	-0.05
C2C		-12.00	-12.08	-0.02	-0.10
C2D		-12.15	-12.22	-0.01	-0.08
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A		-12.72	-12.74	-0.01	-0.03
C4B		-13.22	-13.25	0.00	-0.03

* LIGHT SOURCES: MATH ASSO. #S1850

* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. _______
C2:LC-100G-4-ALHUGH-37 PARA NO. _________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: 2ND CYCLE

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) TEMP @-320F 30 MIN.	TEMP @+396F 30 MIN.	LOW TEMP DEVIATION FROM INITIAL	HIGH TE DEVIATI FROM INITIAL
C1A	-12.11	-11.26	-11.32	-0.02	-0.08
C1B		-13.20	-13.31	0.05	-0.06
C1C		-12.47	-12.41	0.04	0.10
C1D		-12.50	-12.42	-0.12	-0.04
C2A		-11.58	-11.65	0.07	0.00
C2B		-12.85	-12.90	0.04	-0.01
C2C		-12.03	-12.12	-0.05	-0.14
C2D		-12.11	-12.17	0.03	-0.03
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A		-12.70	-12.71	0.01	0.00
C4B		-13.19	-13.22	0.03	0.00

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING __________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ________
C2:LC-100G-4-ALHUGH-37 PARA NO.________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: 3RD CYCLE

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) TEMP @-320F 30 MIN.	TEMP @+396F 30 MIN.	LOW TEMP DEVIATION FROM INITIAL	HIGH TE DEVIATI FROM INITIAL
C1A	-12.11	-11.29	-11.32	-0.05	-0.08
C1B		-13.28	-13.30	-0.03	-0.05
C1C		-12.54	-12.58	-0.03	-0.07
C1D		-12.44	-12.43	-0.06	-0.05
C2A		-11.60	-11.70	0.05	-0.05
C2B		-12.90	-12.96	-0.01	-0.07
C2C		-12.07	-12.23	-0.09	-0.25
C2D		-12.16	-12.20	-0.02	-0.06
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A		-12.72	-12.74	-0.01	-0.03
C4B		-13.23	-13.24	-0.01	-0.02

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. C027FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ________
C2:LC-100G-4-ALHUGH-37 PARA NO.________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: 4TH CYCLE

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm)		LOW TEMP DEVIATION FROM INITIAL	HIGH TE DEVIATI FROM INITIAL
		TEMP @-320F 30 MIN.	TEMP @+396F 30 MIN.		
C1A	-12.11	-11.30	-11.38	-0.06	-0.14
C1B		-13.28	-13.33	-0.03	-0.08
C1C		-12.54	-12.57	-0.03	-0.06
C1D		-12.44	-12.40	-0.06	-0.02
C2A	***	-11.60	-11.74	0.05	-0.09
C2B	***	-12.90	-12.98	-0.01	-0.09
C2C	***	-12.07	-12.15	-0.09	-0.17
C2D	***	-12.16	-12.18	-0.02	-0.04
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A	***	-12.72	-12.73	-0.01	-0.02
C4B	***	-13.23	-13.24	-0.01	-0.02

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.
*** FURCATION TUBING (HYTREL BUFFER PROTECTIVE TUBE) BUFFER WERE SHATTERED RESULTING IN THE KEVLAR STRANDS WITHIN THE TUBE BEING EXPOSED. THE FIBER REMAINED INTACT AND UNDAMAGED.
o THE BRAND REX CABLE DID NOT DEGRADE DURING ANY OF THE TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ______
C2:LC-100G-4-ALHUGH-37 PARA NO. ______
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: 5TH CYCLE

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) TEMP @-320F 30 MIN.	TEMP @+396F 30 MIN.	LOW TEMP DEVIATION FROM INITIAL	HIGH TE DEVIATI FROM INITIAL
C1A	-12.11	-11.32	-11.36	-0.08	-0.12
C1B		-13.30	-13.31	-0.05	-0.06
C1C		-12.55	-12.55	-0.04	-0.04
C1D		-12.40	-12.56	-0.02	-0.18
C2A	***	-11.70	-11.72	-0.05	-0.07
C2B	***	-12.93	-12.96	-0.04	-0.07
C2C	***	-12.10	-12.13	-0.12	-0.15
C2D	***	-12.16	-12.20	-0.02	-0.06
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A	***	-12.72	-12.73	-0.01	-0.02
C4B	***	-13.24	-13.25	-0.02	-0.03

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.
*** FURCATION TUBING (HYTREL BUFFER PROTECTIVE TUBE) BUFFER WERE SHATTERED RESULTING IN THE KEVLAR STRANDS WITHIN THE TUBE BEING EXPOSED. THE FIBER REMAINED INTACT AND UNDAMAGED.
o THE BRAND REX CABLE DID NOT DEGRADE DURING ANY OF THE TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING ______ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH THERMAL SHOCK
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO. ________
C2:LC-100G-4-ALHUGH-37 PARA NO.__________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: POST-TEST (ROOM TEMP)

CHAN NO.	MONITOR (dBm)	MEASUREMENT (dBm) POST MEASUREMENT AFTER 5 CYCLES(ROOM TEMPERATURE)	TEMPERATU DEVIATION FROM INITIAL	AVERAGE	STANDARD DEVIATION
C1A	-12.11	-11.35	-0.11	-11.32	0.03
C1B		-13.29	-0.04	-13.29	-0.04
C1C		-12.55	-0.04	-12.53	-0.04
C1D		-12.54	-0.16	-12.45	-0.16
C2A	***	-11.70	-0.05	-11.67	-0.05
C2B	***	-12.93	-0.04	-12.92	-0.04
C2C	***	-12.09	-0.11	-12.10	-0.11
C2D	***	-12.20	-0.06	-12.17	-0.06
C3A		**			
C3B		**			
C3C		**			
C3D		**			
C4A	***	-12.73	-0.02	-12.72	-0.02
C4B	***	-13.24	-0.02	-13.23	-0.02

* LIGHT SOURCES: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
** GOLD COATED IS BRITTLE AND CRACKED DURING VIBRATION TESTING.
*** FURCATION TUBING (HYTREL BUFFER PROTECTIVE TUBE) BUFFER WERE SHATTERED RESULTING IN THE KEVLAR STRANDS WITHIN THE TUBE BEING EXPOSED. THE FIBER REMAINED INTACT AND UNDAMAGED.
o THE BRAND REX CABLE DID NOT DEGRADE DURING ANY OF THE TESTING.

TEST BY: TEUNIS VISSER DATE: 1/27/94

ENGINEERING __________ DATE:

1 - 5.0 Vibration - random

The vibration tests were conducted in series for x-axis, y-axis and z-axis, with random vibration and sinusoidal vibration for each axis. The tests were conducted per the test plan, Appendix II of this report, para. 2.5.1 and conducted as reported in Appendix III, NTS report. Random Vibration was conducted after salt spray and sinusoidal vibration.

1 - 5.1 Set-up

Test units were subjected to the application of a random vibration spectrum of +6 dB per octave from 20 Hz to 100 Hz and 1.0 g^2/Hz from 100 Hz to 2000 Hz in each of 3 mutually perpendicular axes for not less than 7 minutes per axis.

Change in optical transmittance was monitored by recording 850 nm signal level before, during and after the random vibration test.

Optical signal levels were recorded before, during and after the random vibration testing.

1 - 5.2 Data Sheets

Data sheets follow for x, y, z axes results of random vibration testing. Optical measurements are included.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH RANDOM VIBRATION
ITEM NAME: FIBER OPTIC FEEDTHROUGH
PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36
C2:LC-100G-4-ALHUGH-37
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SAMPLE NO.________
PARA NO.________
SPECIFICATION: X-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm)			CHANGE IN OPTICAL TRANSMITTANCE(dBm)	
			BEFORE	DURING	AFTER	DURING	AFTER
X	C1A	-12.15	-11.20	-11.21	-11.20	-0.01	0.00
	C1B		-13.30	-13.30	-13.32	0.00	-0.02
	C1C		-12.60	-12.64	-12.64	-0.04	-0.04
	C1D		-12.85	-12.83	-12.82	0.02	0.03
	C2A		-11.91	-11.90	-11.92	0.01	-0.01
	C2B		-13.12	-13.14	-13.14	-0.02	-0.02
	C2C		-12.24	-12.28	-12.28	-0.04	-0.04
	C2D		-12.46	-12.46	-12.50	0.00	-0.04
	C3A *		-15.68	-15.70	-15.74	-0.02	-0.06
	C3B *		-13.34	-21.84	-23.20	-8.50	-9.86
	C3C *		-13.81	-19.82	-25.60	-6.01	-11.79
	C3D *		-14.25	-23.60	-29.50	-9.35	-15.25
	C4A		-13.00	-13.00	-13.00	0.00	0.00
	C4B		-13.44	-13.44	-13.46	0.00	-0.02

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE CRACKING.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING____________ DATE____________

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH RANDOM VIBRATION

ITEM NAME: FIBER OPTIC FEEDTHROUGH

PART NO. CO27FT

SERIAL NO.: C1:LC-100G-4-PSP-36

C2:LC-100G-4-ALHUGH-37

C3:LC-100G-4-GPOH-38

C4:LC-100S-D-PSP-32

SAMPLE NO.__________

PARA NO.__________

SPECIFICATION: Y-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm) BEFORE	DURING	AFTER	CHANGE IN OPTICAL TRANSMITTANCE(dBm) DURING	AFTER
Y	C1A	-12.15	-11.20	-11.25	-11.22	-0.05	-0.02
	C1B		-13.33	-13.33	-13.33	0.00	0.00
	C1C		-12.68	-12.70	-12.68	-0.02	0.00
	C1D		-12.91	-12.90	-12.89	0.01	0.02
	C2A		-11.98	-11.80	-11.90	0.18	0.08
	C2B		-13.18	-13.18	-13.18	0.00	0.00
	C2C		-12.28	-12.28	-12.32	0.00	-0.04
	C2D		-12.50	-12.54	-12.52	-0.04	-0.02
	C3A *		-15.20	-17.00	-15.40	-1.80	-0.20
	C3B *		-23.50	-23.50	-23.30	0.00	0.20
	C3C *		-25.80	-25.80	-25.70	0.00	0.10
	C3D *		-27.90	-30.40	-29.50	-2.50	-1.60
	C4A		-13.01	-13.01	-13.01	0.00	0.00
	C4B		-13.46	-13.46	-13.47	0.00	-0.01

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING
READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE CRACKING.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING__________ DATE__________

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH RANDOM VIBRATION
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO.__________
C2:LC-100G-4-ALHUGH-37 PARA NO.__________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: Z-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm)			CHANGE IN OPTICAL TRANSMITTANCE (dBm)	
			BEFORE	DURING	AFTER	DURING	AFTER
Z	C1A	-12.16	-11.24	-11.28	-11.24	-0.04	0.00
	C1B		-13.30	-13.30	-13.30	0.00	0.00
	C1C		-12.66	-12.70	-12.68	-0.04	-0.02
	C1D		-12.80	-12.81	-12.81	-0.01	-0.01
	C2A		-11.85	-11.84	-11.83	0.01	0.02
	C2B		-13.16	-13.16	-13.18	0.00	-0.02
	C2C		-12.28	-12.32	-12.32	-0.04	-0.04
	C2D		-12.48	-12.45	-12.44	0.03	0.04
	C3A *		-21.30	-21.10	-21.00	0.20	0.30
	C3B *		-29.00	-29.00	-29.00	0.00	0.00
	C3C *		-29.30	-31.80	-31.80	-2.50	-2.50
	C3D *		-37.60	-37.60	-37.60	0.00	0.00
	C4A		-13.00	-13.00	-13.02	0.00	-0.02
	C4B		-13.47	-13.48	-13.48	-0.01	-0.01

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING
READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE CRACKING.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94
& 1-13-94
HUMIDITY ________% ENGINEERING__________ DATE__________

1 - 6.0 Vibration - Sinusoidal

Sinusoidal vibration testing was conducted on x, y, z axes per the test plan, Appendix II of this report, para. 2.5.2 and conducted as reported in Appendix III, NTS report. Sinusoidal vibration was conducted after salt spray testing.

1 - 6.1 Set-up

Test units were subjected to the application of sinusoidal vibration, simple harmonic motion in 3 mutually perpendicular axes at a sweep rate of 1 minute per octave from 10 Hz to 2000 Hz to 10 Hz as follows:

A. 10 Hz to 55 Hz at 0.325 inch double amplitude displacement.

B. 55 Hz to 2000 Hz at 50 g's peak.

C. The sweep shall be performed three times in each of three mutually perpendicular directions.

Change in optical transmittance was recorded during and after the exposure to sinusoidal vibration by comparing signal strength to pre-test recorded readings.

1 - 6.2 Data Sheets

Data Sheets follow for x, y, z axes results of sinusoidal vibration testing. Optical measurements are included.

ENGINEERING TEST LABORATORY — GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH SINUSOIDAL VIBRATION

ITEM NAME: FIBER OPTIC FEEDTHROUGH — PART NO. CO27FT

SERIAL NO.: C1:LC-100G-4-PSP-36 — SAMPLE NO.________

C2:LC-100G-4-ALHUGH-37 — PARA NO.________

C3:LC-100G-4-GPOH-38

C4:LC-100S-D-PSP-32

SPECIFICATION: X-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm) BEFORE	DURING	AFTER	CHANGE IN OPTICAL TRANSMITTANCE (dBm) DURING	AFTER
X	C1A	-12.15	-11.20	-11.22	-11.20	-0.02	0.00
	C1B		-13.30	-13.30	-13.30	0.00	0.00
	C1C		-12.60	-12.60	-12.60	0.00	0.00
	C1D		-12.80	-12.85	-12.85	-0.05	-0.05
	C2A		-11.90	-11.90	-11.91	0.00	-0.01
	C2B		-13.12	-13.13	-13.12	-0.01	0.00
	C2C		-12.25	-12.24	-12.24	0.01	0.01
	C2D		-12.46	-12.47	-12.46	-0.01	0.00
	C3A		-15.70	-15.68	-15.68	0.02	0.02
	C3B		-13.34	-13.29	-13.34	0.05	0.00
	C3C		-13.80	-13.80	-13.81	0.00	-0.01
	C3D		-14.27	-14.27	-14.25	0.00	0.02
	C4A		-13.00	-13.02	-13.00	-0.02	0.00
	C4B		-13.45	-13.44	-13.44	0.01	0.01

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE: 1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING________ DATE________

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH SINUSOIDAL VIBRATION
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO.________
C2:LC-100G-4-ALHUGH-37 PARA NO.________
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: Y-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm) BEFORE	DURING	AFTER	CHANGE IN OPTICAL TRANSMITTANCE(dBm) DURING	AFTER
Y	C1A	-12.15	-11.20	-11.20	-11.20	0.00	0.00
	C1B		-13.32	-13.33	-13.33	-0.01	-0.01
	C1C		-12.64	-12.68	-12.68	-0.04	-0.04
	C1D		-12.82	-12.90	-12.91	-0.08	-0.09
	C2A		-11.92	-11.98	-11.98	-0.06	-0.06
	C2B		-13.14	-13.20	-13.18	-0.06	-0.04
	C2C		-12.28	-12.28	-12.28	0.00	0.00
	C2D		-12.50	-12.59	-12.50	-0.09	0.00
	C3A *		-15.74	-15.20	-16.00	0.54	-0.26
	C3B *		-23.20	-23.20	-23.20	0.00	0.00
	C3C *		-25.60	-25.50	-25.60	0.10	0.00
	C3D *		-29.50	-29.00	-29.40	0.50	0.10
	C4A		-13.00	-13.00	-13.01	0.00	-0.01
	C4B		-13.46	-13.46	-13.46	0.00	0.00

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE DEGRADATION.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING________ DATE________

ENGINEERING TEST LABORATORY | GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH SINUSOIDAL VIBRATION
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: C1:LC-100G-4-PSP-36
C2:LC-100G-4-ALHUGH-37
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32
SPECIFICATION: Z-AXIS

PART NO. CO27FT
SAMPLE NO.__________
PARA NO.__________

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm)			CHANGE IN OPTICAL TRANSMITTANCE(dBm)	
			BEFORE	DURING	AFTER	DURING	AFTER
Z	C1A	-12.16	-11.22	-11.24	-11.24	-0.02	-0.02
	C1B		-13.33	-13.30	-13.30	0.03	0.03
	C1C		-12.68	-12.70	-12.66	-0.02	0.02
	C1D		-12.89	-12.86	-12.80	0.03	0.09
	C2A		-11.90	-11.84	-11.85	0.06	0.05
	C2B		-13.18	-13.20	-13.16	-0.02	0.02
	C2C		-12.32	-12.28	-12.28	0.04	0.04
	C2D		-12.52	-12.48	-12.48	0.04	0.04
	C3A *		-21.00	-21.00	-19.60	0.00	1.40
	C3B *		-29.00	-29.00	-28.00	0.00	1.00
	C3C *		-31.80	-31.80	-31.60	0.00	0.20
	C3D *		-35.80	-35.50	-34.80	0.30	1.00
	C4A		-13.01	-13.00	-13.00	0.01	0.01
	C4B		-13.47	-13.47	-13.47	0.00	0.00

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING
·READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE DEGRADATION.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING__________ DATE__________

1 - 7.0 Mechanical Shock

The mechanical shock test was conducted on x, y, z axes per the test plan, Appendix II of this report, para. 2.6 and conducted as reported in Appendix II, NTS report. Shock testing was conducted after salt spray, and vibration tests.

1 - 7.1 Set-up

Test units were subjected to 3 shocks (40 G's, 11±1 millisecond half sine) in each direction of 3 mutually perpendicular axes.

The forces were produced by securing the connectors to a sufficient mass and accelerating or decelerating the assembly so that the specified force was obtained. Three shock pulses were applied in each direction of each of the three major axes. The cable was clamped to points that move with the feedthrough. A minimum of 8 inches of cable were unsupported behind the rear of each feedthrough.

The testing was conducted in accordance with EIA/TIA-455-14 "Fiber Optic Shock Test". Change in optical transmittance was monitored by recording 850 nm signal level before, during and after the shock test.

Change in optical transmittance was recorded for the mechanical shock test after completion of the test.

1 - 7.2 Data Sheets

Data is recorded on the following sheet for the x-y-z simultaneous pulse shock test. Optical measurements are included.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH MECHANICAL SHOCK

ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT

SERIAL NO.: C1:LC-100G-4-PSP-36 SAMPLE NO.________

C2:LC-100G-4-ALHUGH-37 PARA NO.________

C3:LC-100G-4-GPOH-38

C4:LC-100S-D-PSP-32

SPECIFICATION: XYZ-AXIS

AXIS	CHANNEL NO.	MONITOR (dBm)	ATTENUATION (dBm)			CHANGE IN OPTICAL TRANSMITTANCE(dBm)	
			BEFORE	DURING	AFTER	DURING	AFTER
XYZ	C1A	-12.2	-11.34		-11.30		0.04
	C1B		-13.40		-13.40		0.00
	C1C		-12.78		-12.70		0.08
	C1D		-12.90		-12.92		-0.02
	C2A		-11.92		-12.00		-0.08
	C2B		-13.30		-13.39		-0.09
	C2C		-12.44		-12.50		-0.06
	C2D		-12.53		-12.57		-0.04
	C3A *		-21.20		-45.40		-24.20
	C3B *		-29.18		-54.10		-24.92
	C3C *		-32.00		-59.30		-27.30
	C3D *		-37.80		-59.00		-21.20
	C4A		-13.16		-13.19		-0.03
	C4B		-13.60		-13.62		-0.02

*GOLD-COATED FIBER IS BRITTLE AND CRACKED DURING VIBRATION TESTING READINGS HERE SHOW EXCESSIVE LOSS BECAUSE OF THE CRACKING.

TEMPERATURE ________F TESTED BY: TEUNIS VISSER DATE:1-12-94 & 1-13-94

HUMIDITY ________% ENGINEERING________ DATE________

1 - 8.0 Salt Spray

Salt Pray testing was conducted per the test plan, Appendix II of this report, para. 2.8, and conducted as reported in Appendix III, NTS report. Salt spray was the first test on this group of feedthrough units C1, C2, C3, C4.

1 - 8.1 Set-up

The developed feedthrough test units were exposed to a salt spray environment, both Type I and Type II feedthroughs. The test units were subjected to 96 hours of salt spray testing in accordance with MIL-STD-202, Method 101, Test Condition B, using a 5 percent by weight salt solution. Immediately after exposure, the exterior surface and the mating face of the test specimens were thoroughly washed with tap water. The specimen was then inspected with 4X magnification and showed no evidence of exposure of basis metal nor indication of corrosion products.

Change in Optical Transmittance was monitored by recording 850 nm signal level before, during and after the salt spray test. Comparison was made between initial (pre-test) readings and subsequent readings.

1 - 8.2 Data Sheets

Data is recorded on the following sheet for the salt spray test. Optical measurements are included. Photographs follow which show test specimens after the salt spray test.

ENGINEERING TEST LABORATORY　　　　GENERAL DATA SHEET

TEST: OPTICAL TRANSMITTANCE TEST WITH SALT SPRAY
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: C1:LC-100G-4-PSP-36
C2:LC-100G-4-ALHUGH-37
C3:LC-100G-4-GPOH-38
C4:LC-100S-D-PSP-32

PART NO. CO-27FT
SAMPLE NO.
PARA NO.

SPECIFICATION:

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm) @12:15 1/4/94	MEASUREMENT (dBm) @12:15 1/4/94	@13:45 1/4/94	@16:15 1/4/94	@07:15 1/5/94	@16:00 1/5/94	@06:45 1/6/94	@15:15 1/6/94	@11:50 1/8/94	AVERAGE	STANDARD DEVIATION
C1A	-12.07	-11.86	-11.86	-11.81	-11.82	-11.81	-11.81	-11.82	-11.80	-11.81	-11.83	0.02
C1B	-12.07	-13.31	-13.31	-13.45	-13.40	-13.37	-13.37	-13.37	-13.35	-13.37	-13.37	0.01
C1C	-12.07	-12.54	-12.54	-12.54	-12.51	-12.50	-12.50	-12.59	-12.57	-12.57	-12.54	0.03
C1D	-12.07	-12.10	-12.10	-12.42	-12.40	-12.12	-12.10	-12.45	-12.40	-12.42	-12.11	0.02
C2A	-12.07	-11.70	-11.70	-11.70	-11.72	-11.72	-11.73	-11.73	-11.71	-11.70	-11.71	0.01
C2B	-12.07	-12.92	-12.92	-12.85	-12.83	-12.84	-12.87	-12.90	-12.86	-12.87	-12.87	0.03
C2C	-12.07	-12.05	-12.05	-11.91	-12.00	-12.00	-12.00	-12.13	-12.13	-12.11	-12.05	0.07
C2D	-11.96	-12.53	-12.53	-12.53	-12.55	-12.53	-12.51	-12.50	-12.50	-12.52	-12.52	0.02
C3A	-11.97	-15.47	-15.48	-15.48	-15.51	-15.50	-15.50	-15.53	-15.55	-15.57	-15.52	0.03
C3B	-11.96	-13.00	-13.00	-13.00	-13.05	-13.04	-13.00	-13.01	-13.00	-13.01	-13.01	0.02
C3C	-12.07	-13.96	-13.96	-13.92	-13.92	-13.94	-13.91	-13.94	-13.94	-13.94	-13.91	0.01
C3D	-12.07	-14.12	-14.12	-14.12	-14.16	-14.16	-14.14	-14.14	-14.10	-14.10	-14.13	0.02
C4A	-12.07	-12.88	-12.75	-12.70	-12.75	-12.75	-12.75	-12.75	-12.70	-12.73	-12.73	0.02
C4B	-11.96	-13.31	-13.27	-13.27	-13.27	-13.29	-13.29	-13.25	-13.22	-13.23	-13.26	0.02

* LIGHT SOURCE: MATH ASSO. #S185
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: TEUNIS VISSER　　DATE: JANUARY 4 TO 8, 1994

ENGINEERING ____________　　DATE:

1 - 9.0 Humidity

Humidity testing was conducted per the test plan, Appendix II of this report, para. 2.9. Humidity testing was conducted after radiation hardening test.

1 - 9.1 Set-up

Type 1 and Type 2 feedthrough units were tested in a humidity exposure environment. The units were subjected to 240 hours of exposure to 98-100% humidity at 104°F (+40°C) to 140°F (+60°C). Prior to the humidity exposure, the specimens were conditioned.

A. Conditioning - condition specimens at +45°C to +55°C (+113°F to +131°F) for 24 hours and return to room ambient temperature prior to beginning humidity exposure. Measure and record optical transmittance at room ambient temperature before and after conditioning.

B. Exposure - Subject test items to the temperature and humidity conditions described above for 240 hours exposure. Measure and record optical transmittance before, during and after humidity exposure. Record at end of each 24-hour period.

Change in optical transmittance was recorded for feedthroughs C1, C2, C3, C4 using 850 nm signals by comparing monitored readings during the humidity test and final readings to the initial readings.

1 - 9.2 Data Sheets

Data is recorded on the following sheet for the humidity test. Optical measurements are included.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: HUMIDITY TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33

PART NO. CO-27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: THE UNITS ARE SUBJECTED TO 240 HRS OF EXPOSURE TO 98-100% HUMIDITY AT 104F TO 140F

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm) 24 HRS @50 C TEMP BEFORE @8:45 2/10/94	AFTER @12:30 2/11/94	MEASUREMENT (dBm) 98-100% HUMIDITY @ TEMPERATURE 122 DEGREE F @16:02 2/11/94	@16:10 2/12/94	@16:15 2/13/94	@16:30 2/14/94	@16:35 2/15/94	@16:36 2/16/94	@16:40 2/17/94	@16:43 2/18/94	@16:48 2/19/94	@16:52 2/20/94	@17:06 2/21/94	AVERAGE	STANDARD DEVIATION
A-A	-11.70	-11.14	-11.16	-11.16	-11.16	-11.11	-11.13	-11.13	-11.14	-11.14	-11.13	-11.13	-11.12	-11.12	-11.14	0.01
A-B		-11.27	-11.26	-11.27	-11.27	-11.28	-11.28	-11.27	-11.29	-11.30	-11.30	-11.29	-11.30	-11.29	-11.29	0.01
B-A		-11.40	-11.40	-11.40	-11.16	-11.46	-11.43	-11.43	-11.42	-11.12	-11.13	-11.43	-11.42	-11.42	-11.43	0.02
C-A		-11.52	-11.51	-11.51	-11.51	-11.54	-11.54	-11.53	-11.50	-11.50	-11.51	-11.49	-11.49	-11.49	-11.51	0.02
D-A		-11.80	-11.80	-11.80	-11.77	-11.77	-11.82	-11.83	-11.85	-11.85	-11.87	-11.87	-11.86	-11.86	-11.83	0.01
D-B		-12.00	-11.98	-11.98	-12.03	-12.03	-12.06	-12.06	-12.07	-12.02	-12.02	-12.05	-12.05	-12.06	-12.04	0.03
D-C		-11.94	-11.96	-11.96	-11.95	-11.98	-12.00	-12.00	-12.02	-11.98	-11.98	-11.94	-11.92	-11.98	-11.97	0.03
D-D		-11.15	-11.18	-11.18	-11.20	-11.17	-11.17	-11.16	-11.19	-11.20	-11.21	-11.17	-11.21	-11.21	-11.19	0.02

* LIGHT SOURCE: MATH ASSO. #S1850
* DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: TEUNIS VISSER DATE: FEBRUARY 10 TO 21, 1994

ENGINEERING ____________ DATE:

1 - 10.0 Neutron Fluence Radiation

Neutron Fluence Radiation testing was conducted on feedthrough units A, B, C, D. Testing was per the test plan, Appendix II of this report, para. 2.7. Test details are described in Appendix VI of this report. Neutron Fluence was the first of the radiation tests conducted.

1 - 10.1 Set-up

Type 1 and Type 2 feedthrough units were exposed to the neutron irradiation for 6 hours at a target fluence level of $1x10^{12}$ neutrons/cm^2. Test units were rotated at approx. 4 RPM during exposure.

Change in optical transmittance was recorded for feedthroughs A, B, C, D using 850 nm signals by comparing readings before and after the neutron irradiation.

1 - 10.2 Data Sheets

The following data sheet records test results. Optical measurements and radiation exposure data are included.

ENGINEERING TEST LABORATORY

GENERAL DATA SHEET

TEST: NEUTRON FLUENCE TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT 10^12 NEUTRONS/CM^2

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)		CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-11.3	-11.86	-11.83	*	0.03
B-A		-11.82	-11.85	*	-0.03
C-A		-11.90	-11.98	*	-0.08
D-A		-11.18	-11.24	*	-0.06
D-B		-11.78	-11.82	*	-0.04
D-C		-9.72	-9.81	*	-0.09
D-D		-11.56	-11.63	*	-0.07

LIGHT SOURCE: MATH ASSO. #S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C
* DUE TO STAINLESS STEEL SPRING HAVING RESIDUAL RETAINED IN ST TYPE COMMERCIAL CONNECTORS, NEW ST'S INSTALLED AFTER NEUTRON FLUENCE TEST.

TEST BY: TEUNIS VISSER DATE: JANUARY 31, 1994

ENGINEERING ____________ DATE:

1 - 11.0 Gamma Radiation

Gamma Radiation testing was conducted on feedthrough units A, B, C, D. Testing was per the test plan, Appendix II of this report, para. 2.7. Test details are described in Appendix VI of this report. Gamma Radiation was the second of the radiation tests conducted.

1 - 11.1 Set-up

Type I and Type II feedthroughs were exposed to the gamma flash x-ray dosage as described in Appendix VII.

Change in optical transmittance was measured by comparing initial signal levels prior to test to the final signal levels at the end of the test. Also, optical signal change due to influence of radiation exposure was recorded as shown in Appendix I. The exposure dose rate levels are shown in Appendix VII, Table 2.

1 - 11.2 Data Sheets

The following data sheets record test results. Optical measurements and radiation exposure data are included. Note on the Rockwell Radiation Effects data sheets, the "Signal (Expanded)" plot is representing noise in the machine which was an anomaly. However, since the time is over $200x10^{-9}$sec, it does not influence the recovery of fiber trace "Signal" on each sheet. Photographs of the test set up follow.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: GAMMA DOSE RATE TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: B:LC-100S-D-PSP-33

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL UP TO 10^9 Rads(Si)/sec GAMMA DOSE RATE

CHAN NO.	SHOT NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
B-A	1	-11.3	-11.82	-11.82	0.00
	2		-11.82	-11.82	0.00
	3		-11.82	-11.77	0.05
	4		-11.82	-11.75	0.07
	5		-11.82	-11.75	0.07
	6		-11.82	-11.77	0.05
	7		-11.82	-11.75	0.07
	8		-11.82	-11.75	0.07
	9		-11.82	-11.73	0.09
	10		-11.82	-11.68	0.14
	11		-11.82	-11.65	0.17
	12		-11.82	-11.67	0.15
	13		-11.82	-11.67	0.15
	14		-11.82	-11.66	0.16

LIGHT SOURCE: MATH ASSO. #S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON DATE: FEBRUARY 1, 1994

ENGINEERING __________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: GAMMA DOSE RATE TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: A:LC-100G-D-ALHUGH-39 SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL UP TO 10^9 Rads(Si)/sec GAMMA DOSE RATE

CHAN NO.	SHOT NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-B	15	-11.3	-11.94	-11.92	0.02
	16			-11.98	-0.04
	17			-11.97	-0.03
	18			-11.98	-0.04

LIGHT SOURCE: MATH ASSO. #S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON DATE: FEBRUARY 1, 1994

ENGINEERING ___________ DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: GAMMA DOSE RATE TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: C:LC-100G-4-GPOLY-38

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL UP TO 10^9 Rads(Si)/sec GAMMA DOSE RATE

CHAN NO.	SHOT NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
C-A	19	-11.3	-11.90	-11.80	0.10
	20			-11.93	-0.03
	21			-11.95	-0.05
	22			-11.93	-0.03

LIGHT SOURCE: MATH ASSO. #S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON DATE: FEBRUARY 1, 1994

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY — GENERAL DATA SHEET

TEST: GAMMA DOSE RATE TEST
ITEM NAME: FIBER OPTIC FEEDTHROUGH — PART NO. CO27FT
SERIAL NO.: D:LC-100G-4-PSP-33 — SAMPLE NO.
PARA NO.
SPECIFICATION: RADIATION HARDENING TEST LEVEL UP TO 10^9 Rads(Si)/sec GAMMA DOSE RATE

CHAN NO.	SHOT NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
D-A	23	-11.3	-11.24	-11.18	0.06
	24			-11.15	0.09
	25			-11.07	0.17
	26			-11.08	0.16

LIGHT SOURCE: MATH ASSO. #S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON — DATE: FEBRUARY 1, 1994

ENGINEERING ___________ DATE:

Litecom

FACILITY FXR (X-RAY) TEST ENGR'S AC/JN/MS/R.Fan DATE 2-1-94

PART TYPE Fiber Optic Feedthru ~~PROGRAM~~

VENDOR Litecom ~~D/C~~ P/N CØ27FT S/N: LC-1006-II-PSP-33

~~VDD~~ PULSE WIDTH ~17ns

+1.25 in

Shot No.	TABLE POSIT. (in)	DOSE (rad(Si))	CUM. DOSE (rad(Si))	DOSE RATE (rad/s)	S/N	DATA d.c.		tpw (ns)	trec (µs)	COMMENTS
1	23	~1.7		[illegible] ~~[illegible]~~	1	-29mv				Amplitude too low for signal [illegible]
2		~1.7		[illegible] ~~[illegible]~~						Intensity need [illegible]
3		1.7		[illegible] ~~1.00E9~~						
4		~1.7		~1E9 *						* PL BRICKS in front of x-ray. "NOISE SHOT"
5		~1.7	~8.5	~1E9 *						* PL BRICK + [illegible] Al → PL [illegible] 0.2V/[illegible]
6		2.1	10.6	[illegible]E7 ~~[illegible]E8~~				17.6		Repeat Real Shot 0.[illegible]
7		2.6	13.2	9.60E7 ~~[illegible]E8~~				18.0		Repeat Shot 0.[illegible]/10V
8	9	9.7	22.9	5.72E8				19.5		
9		10.0	32.9	5.90E8				19.9		Repeat [illegible] for d.c. Level
10		9.5	42.4	5.[illegible]E8				20.3		1) GND FXR 2) [illegible] Filter Cables
11		8.9	51.3	5.[illegible]E8				20.7		GND on FXR Removed
12	6	19.0	70.3	1.1[illegible]E9				21.1		
13	2.5	~85	155	~4.5E9				–		
14		86.39	242	4.55E9 ~~5.09E9~~				–		T=12 L ~~[illegible]~~ rad R 86.3923

Litecom

FACILITY ______ TEST ENGR's ______ DATE 2-1-94

PART TYPE ______ ~~PROGRAM~~ ______

VENDOR Litecom P/N ~~D/C~~ C∅27FT S/N: LC-100G-D-ALHUGH-3

~~VDD~~ ______ PULSE WIDTH ~17ns

Shot No.	TABLE POSIT. (in)	DOSE (rad(Si))	CUM. DOSE (rad(Si))	DOSE RATE (rad/s)	S/N	DATA d.c.	DATA	DATA t_{pw} (ns)	DATA t_{REC} (μs)	COMMENTS
15	23	3.3		1.22 ~~1.95~~ E8	2	-39mV		15.6		
16	7	9.1	12.4	5.33E8				19.7		
17	6	17.9	30.3	1.05E9				21.9		
18	2.5	71.14	101	3.74E9 ~~4.60E7~~				—		L 91.4895 (SN #2) R 74.7914

FACILITY ____________ TEST ENGR'S ____________ DATE ____________

PART TYPE ____________ ~~PROGRAM~~ ____________

VENDOR ____________ P/N ~~D/C~~ ____________ S/N: LC-1006-4-GPOLY-3E

~~VDD~~ ____________ PULSE WIDTH ~17 ns ____________

Shot No.	TABLE POSIT. (in)	DOSE (rad(Si))	CUM. DOSE (rad(Si))	DOSE RATE (rad/s)	S/N	DATA d.c.	DATA	DATA t_{pw} (ns)	DATA t_{rec} (µs)	COMMENTS
19	~3	3.4		1.26E9	3	-29mV		17.2		
20	9	9.5	12.9	5.00E8				20.3		
21	6	19.7	32.6	1.16E9				22.3		
22	2.5	84.1	117	9.43E9				–		L = 94.5404 R = 73.6308 } 84.085

Litecom

FACILITY ______ TEST ENGR'S ______ DATE ______

PART TYPE ______ PROGRAM ______

VENDOR Litecom ~~D/C~~ P/N CØ27FT S/N: LC-100G-4-PSP-33

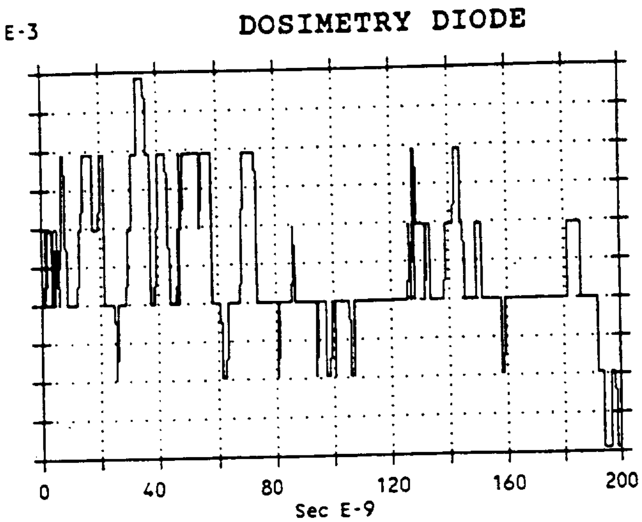
~~VDD~~ ______ PULSE WIDTH ~17ns

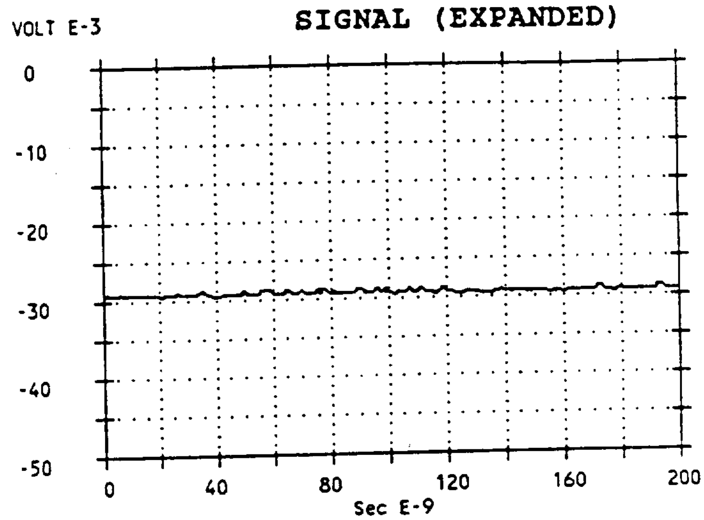
Shot No.	TABLE POSIT. (in)	DOSE (rad(Si))	CUM. DOSE (rad(Si))	DOSE RATE (rad/s)	S/N	DATA d.c.		t_{pw} (ns)	t_{rec} (μs)	COMMENTS
23	23	3.7		~~2.17~~ 1.35 E8	4	-30.5 mV		14.8		
24	9	10.3	14.0	6.06E9				18.4		
25	6	20.7	34.7	1.22E9				21.1		
26	2.5	78.0	113	~~4.59~~ 4.11 E9				—		1 = 83.1079, 2 = 72.9235 } 78.0157

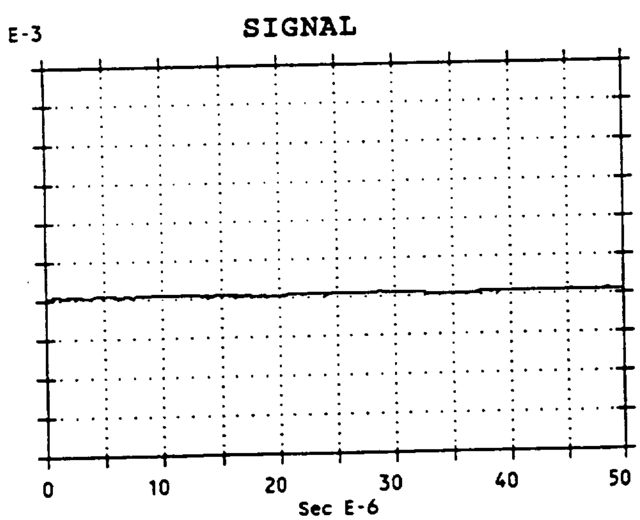
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #: C027FT
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~3.553625E-02~~
DOSE RATE: ~~4135128~~
PULSE WIDTH: 8.593 ns
CAL FACTOR: ~~68699264~~ rad/volt-sec
42937037







FACEPLATE DISTANCE 23"

S/N LC-100S-D-PSP-33

SHOT 0

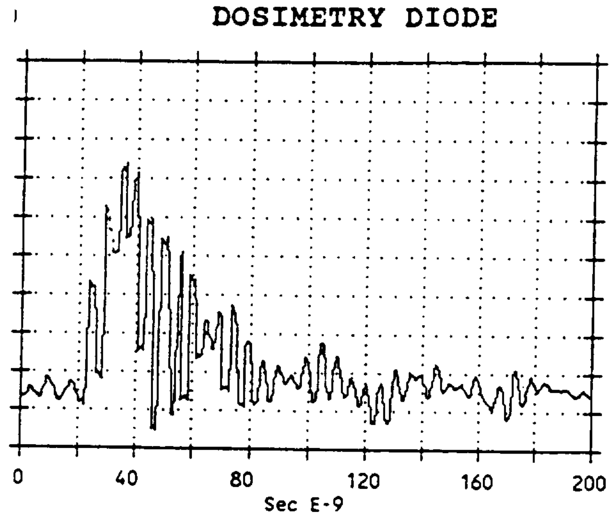
1:25:03

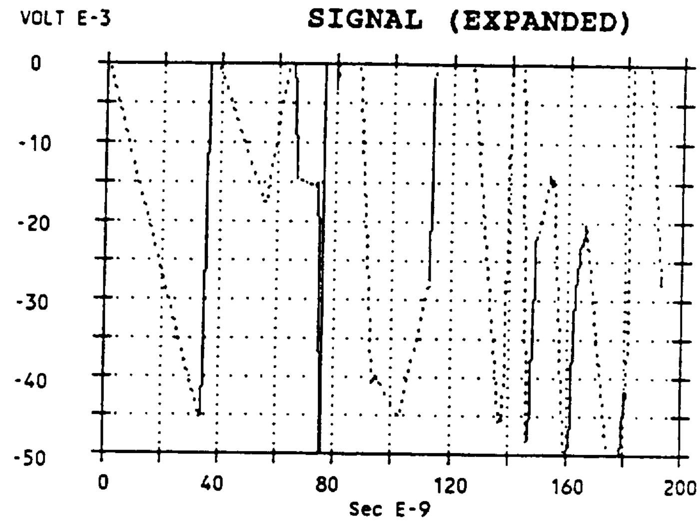
02-01-1994

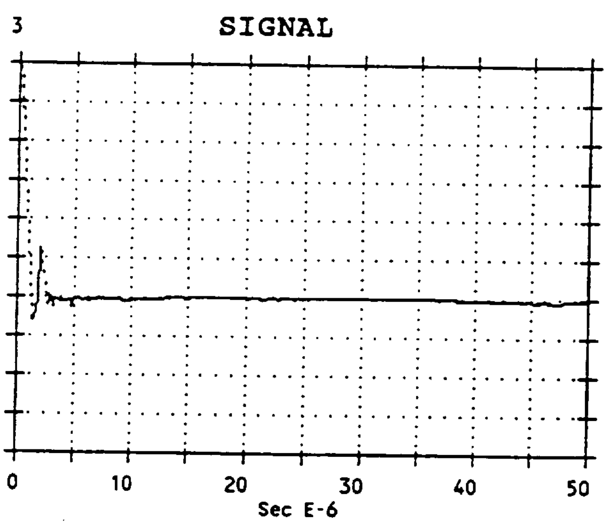
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #: C027FT
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 1.140725
DOSE RATE: ~~8.849259~~ 2.3352 E+07
PULSE WIDTH: 12.89 ns
CAL FACTOR: ~~68699264~~ 42937037 rad/volt-sec







FACEPLATE DISTANCE 23"

S/N LC-100S-D-PSP-33

SHOT 1

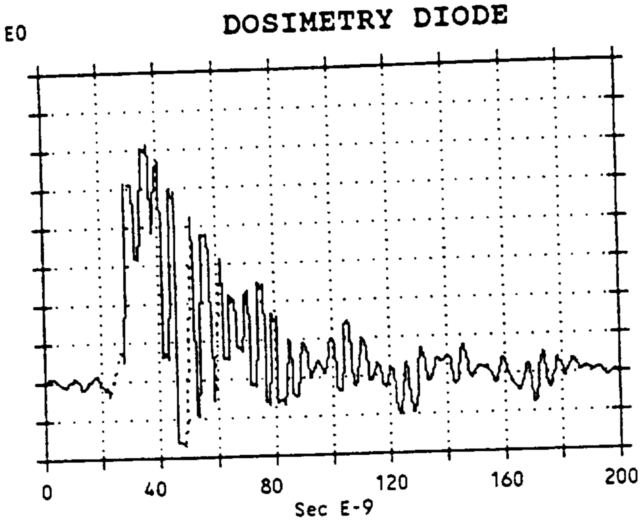
1:27:20 02-01-1994

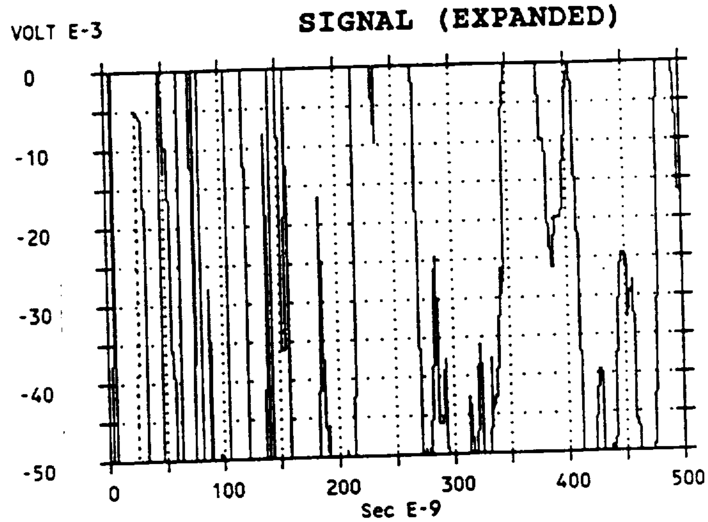
PAGE 1

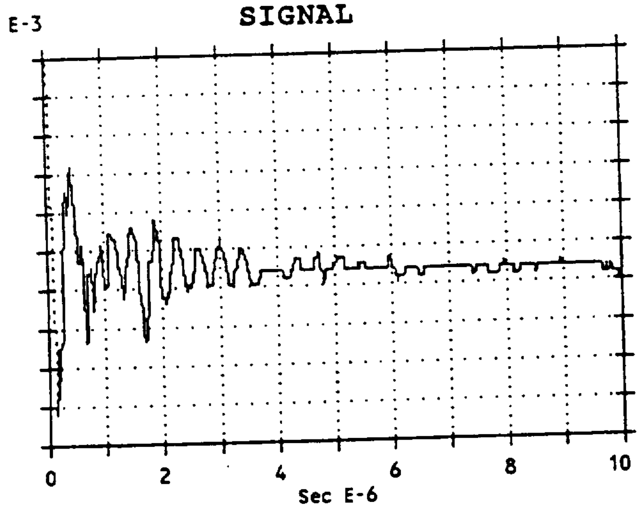
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #: C027FT
MANUFACTURER: LITECOM
DATE CODE:

DOSE: .7399721
DOSE RATE: 7.48222 ~~5.571555~~E+07
PULSE WIDTH: 13.28 ns
CAL FACTOR: ~~68699264~~ 42937037 rad/volt-sec







FACEPLATE DISTANCE 23"

SHOT 2

S/N LC-100S-D-PSP-33

PAGE 1

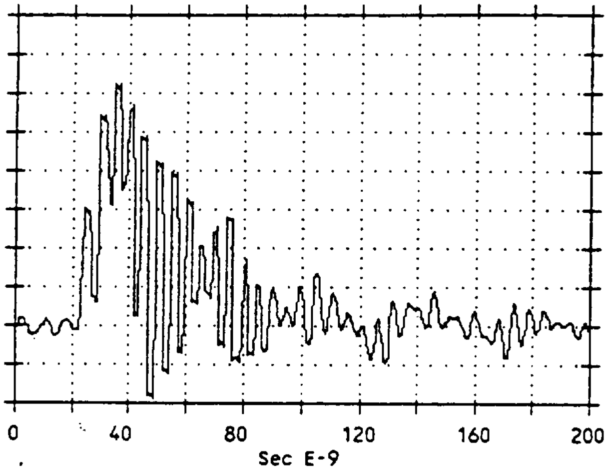
1:33:28 02-01-1994

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

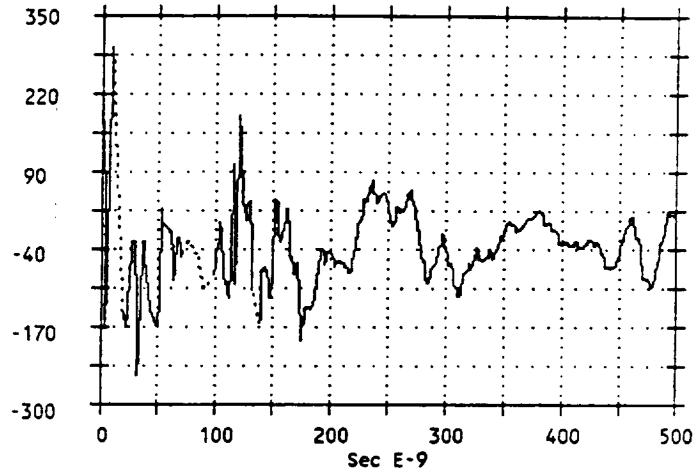
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: .7837897
DOSE RATE: ~~1.003251~~ 6.270319 E+0~~8~~7
PULSE WIDTH: 7.812 ns
CAL FACTOR: ~~68699264~~ 42537037 rad/volt-sec

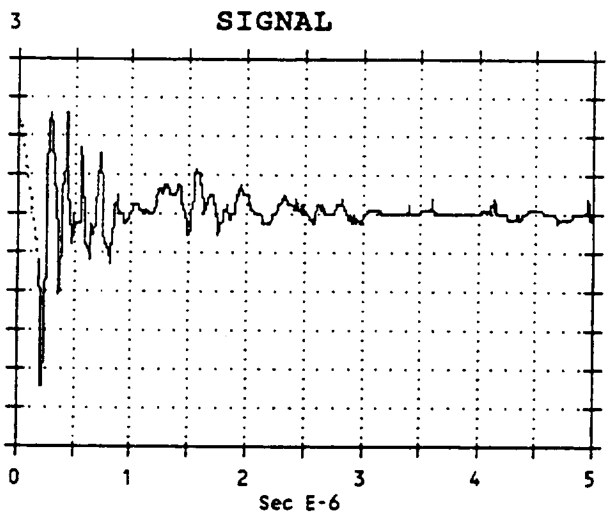
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



S/N LC-100S-D-PSP-33

SHOT ~~2~~3

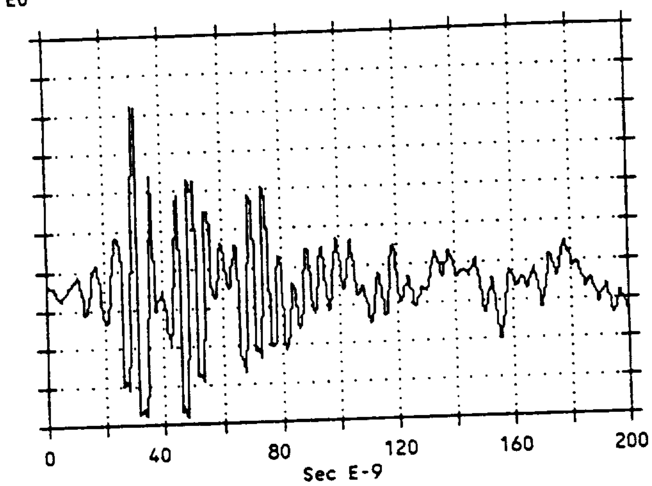
1:58:03 02-01-1994

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

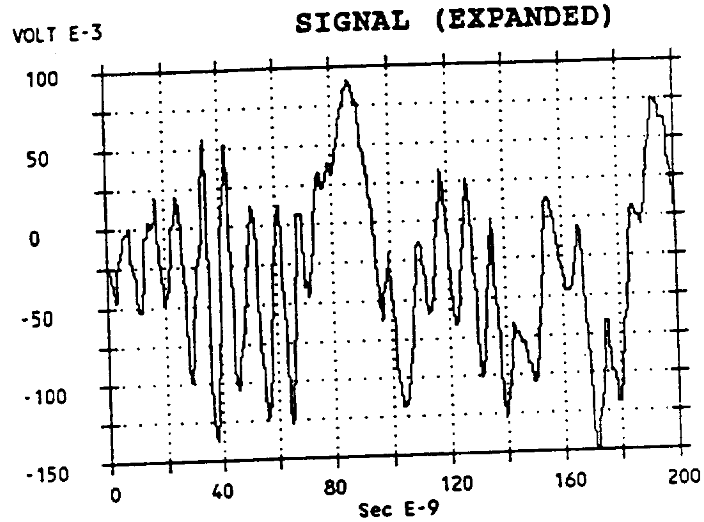
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: .1069233
DOSE RATE: ~~9438745~~
PULSE WIDTH: 11.32 ns
CAL FACTOR: ~~68699264~~ rad/volt-sec
42937037

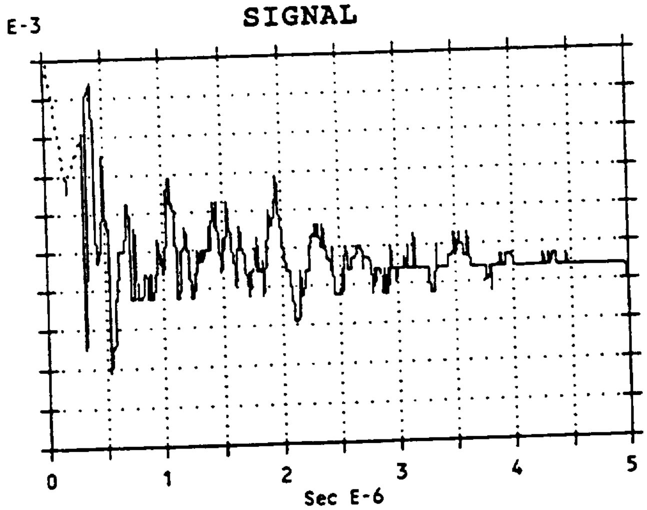
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



2" Pb INFRONT OF FXR

SHOT ~~5~~ 4

S/N LC-100S-D-PSP-33

274

PAGE 1

2:12:05

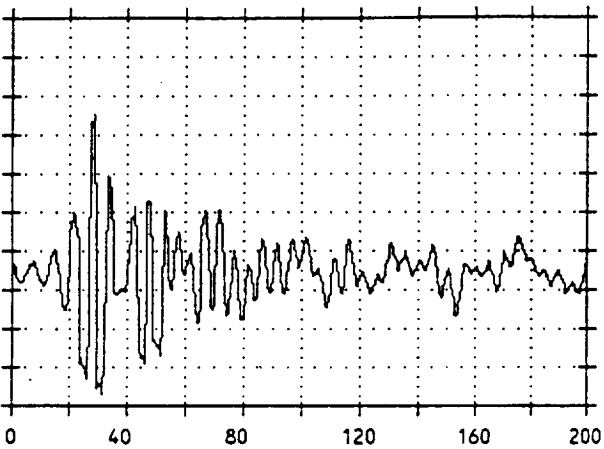
02-01-1994

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

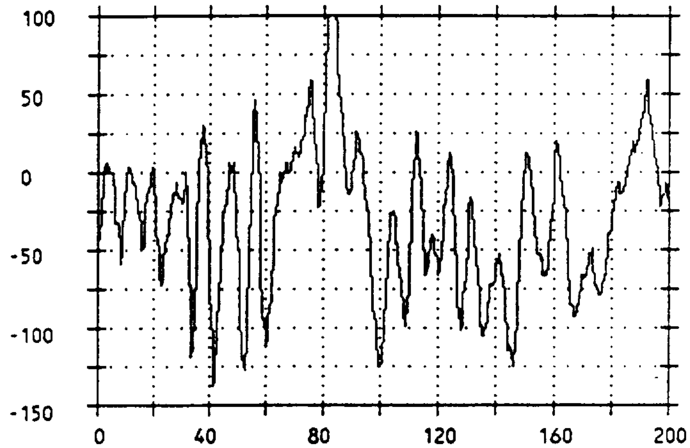
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 1.635298E-02
DOSE RATE: ~~1443573~~
PULSE WIDTH: 11.32 ns
CAL FACTOR: ~~68699264~~ rad/volt-sec
42937037

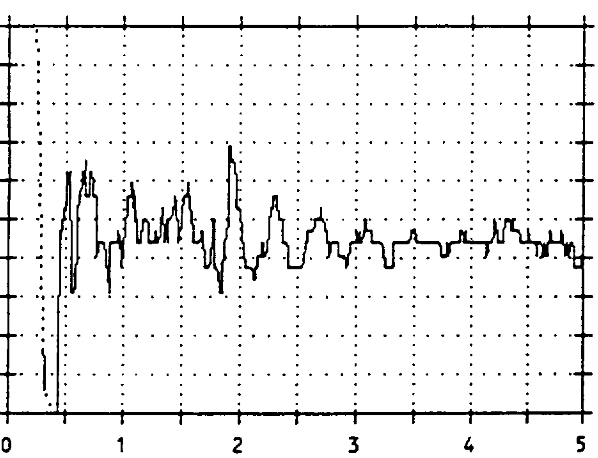
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



2" Pb INFRONT OF FXR + SHEET Al

S/N LC-100S-D-PSP-33

SHOT 5

2:20:34

02-01-1994

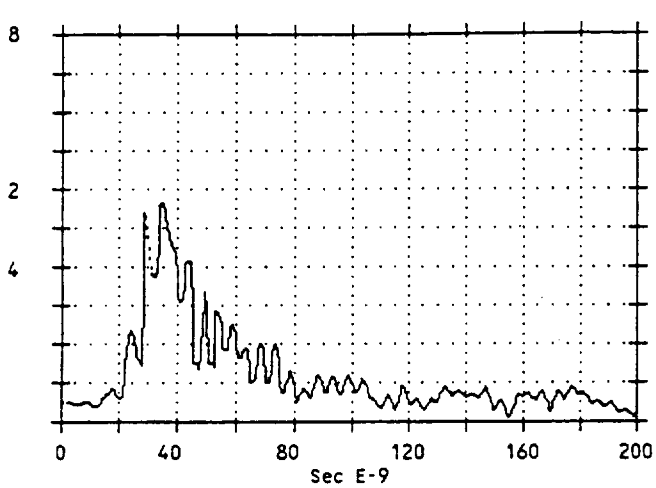
PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

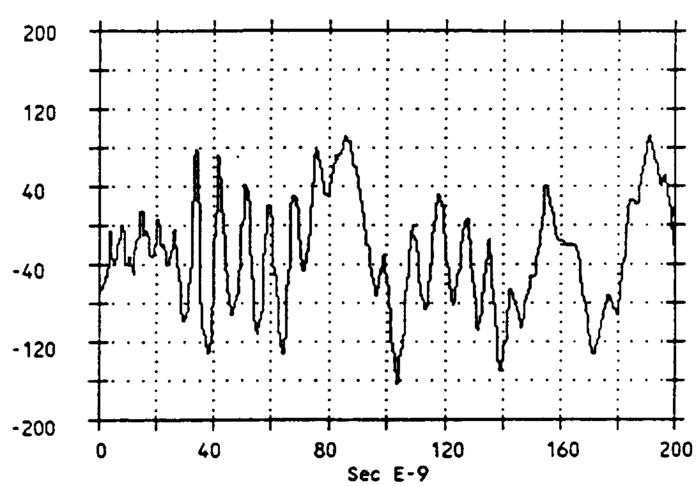
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 2.222642
DOSE RATE: ~~1.264436~~E+08
PULSE WIDTH: 17.57 ns
CAL FACTOR: ~~68699264~~ rad/volt-sec
42937037

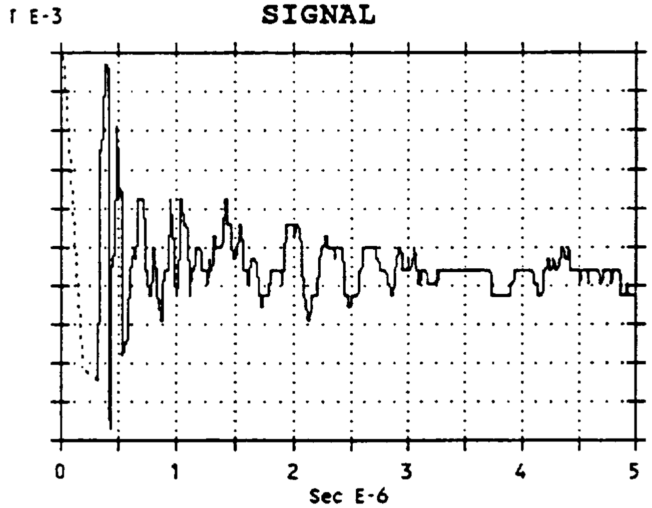
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



FACEPLATE DISTANCE 23"

S/N LC-100S-D-PSP-33

SHOT 6

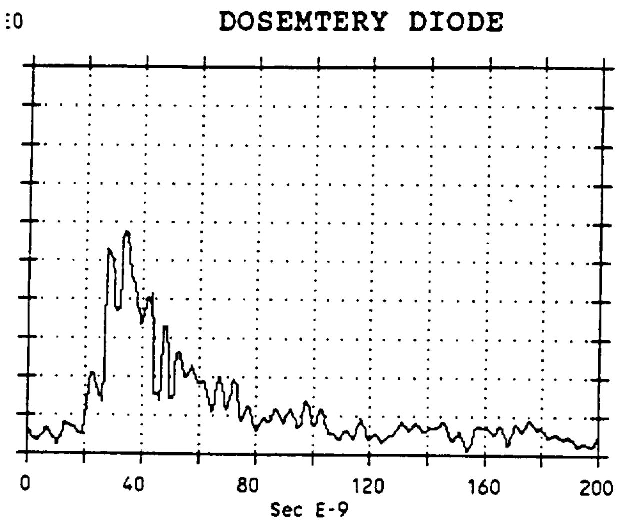
2:28:19 02-01-1994

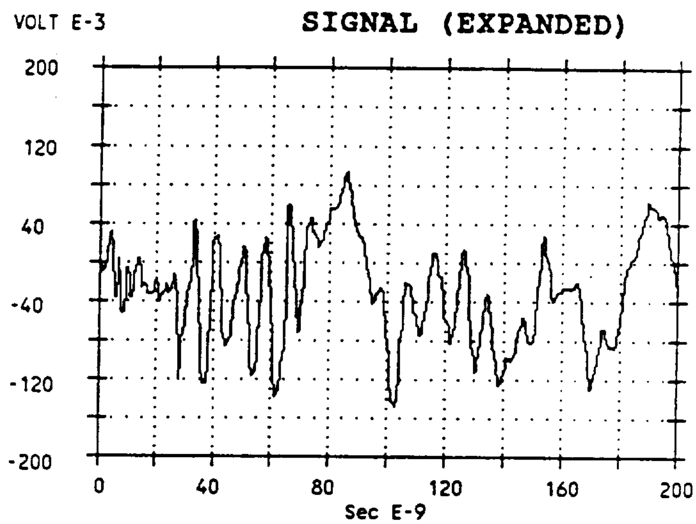
PAGE 1

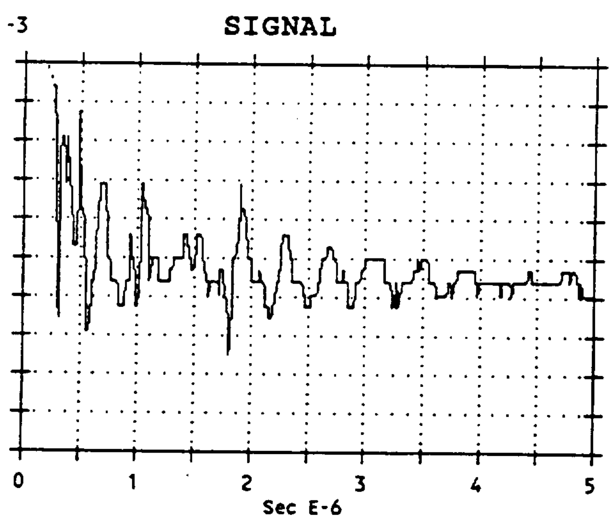
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 2.759461
DOSE RATE: 9.5798 ~~1.5357~~E+08 7
PULSE WIDTH: 17.96 ns
CAL FACTOR: ~~68699264~~ 42937037 rad/volt-sec







FACEPLATE DISTANCE 23"

S/N LC-100S-D-PSP-33

277

SHOT ~~6~~ 7

2:29:12

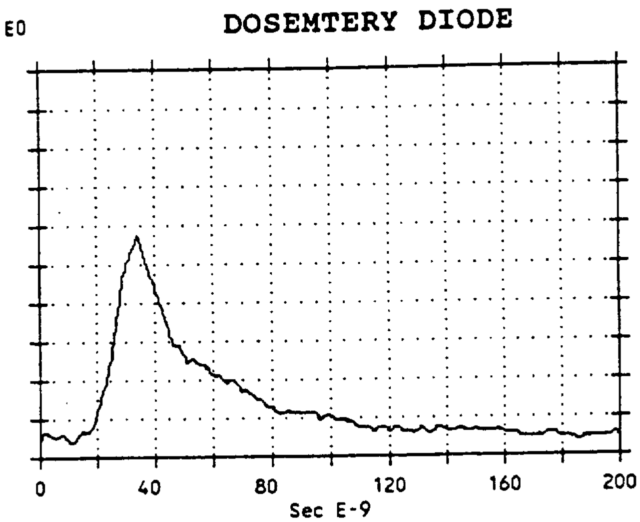
02-01-1994

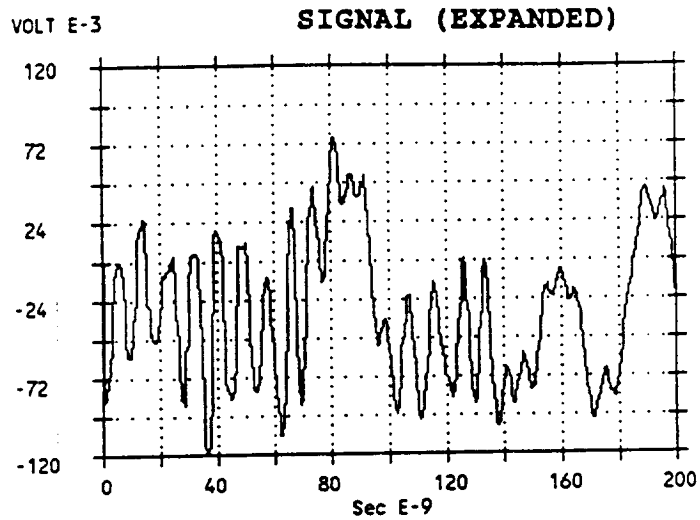
PAGE 1

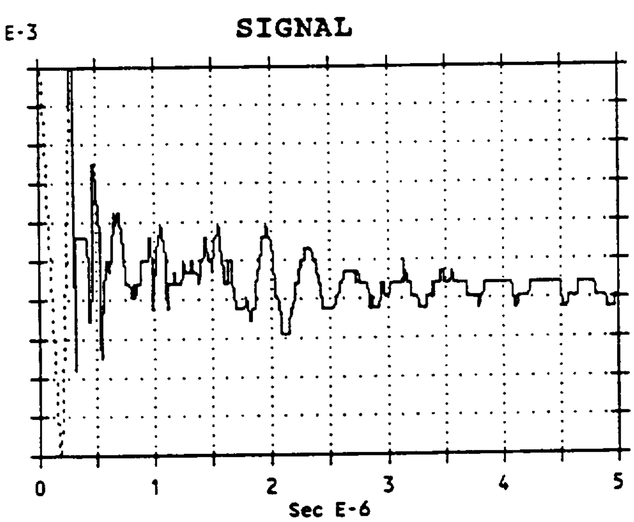
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 11.16331
DOSE RATE: 5.715612E+08
PULSE WIDTH: 19.53 ns
CAL FACTOR: 36325640 rad/volt-sec







FACEPLATE DISTANCE 9"

S/N LC-100S-D-PSP-33

SHOT 8

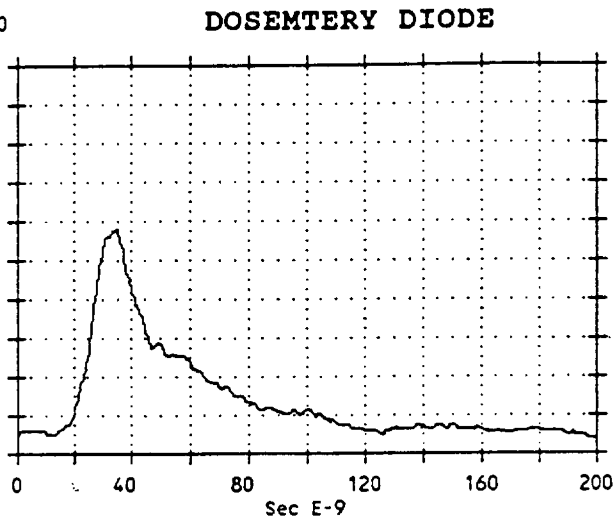
2:39:55 02-01-1994

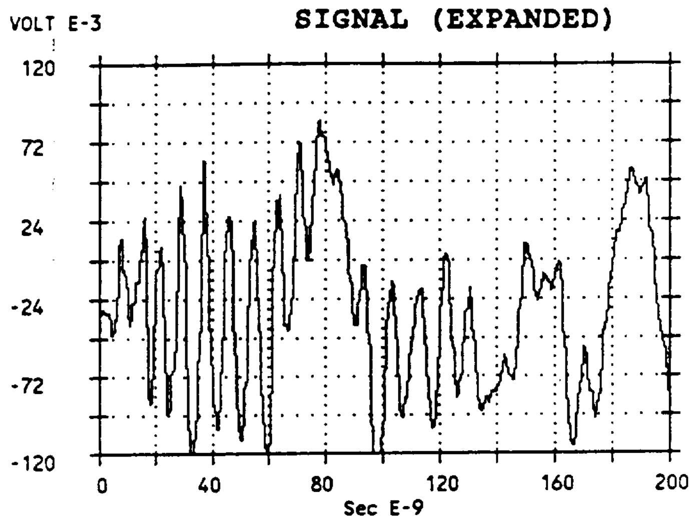
PAGE 1

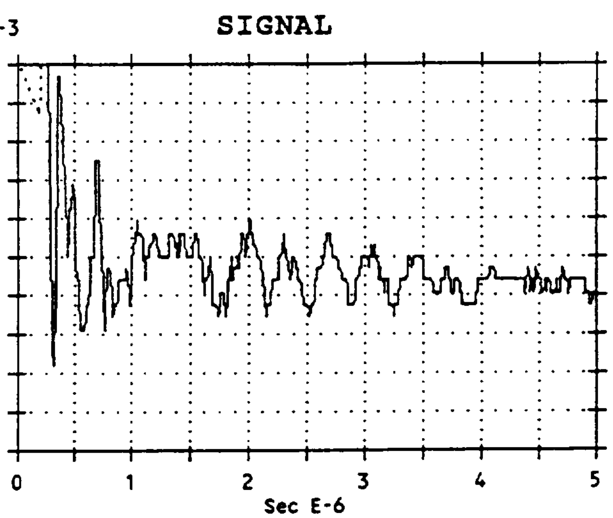
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 11.75195
DOSE RATE: 5.899018E+08
PULSE WIDTH: 19.92 ns
CAL FACTOR: 36325640 rad/volt-sec







FACEPLATE DISTANCE 9"

S/N LC-100S-D-PSP-33

SHOT 9

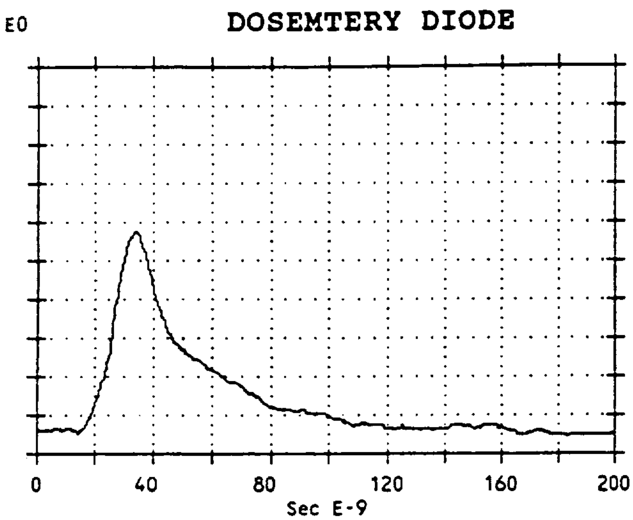
2:45:53 02-01-1994

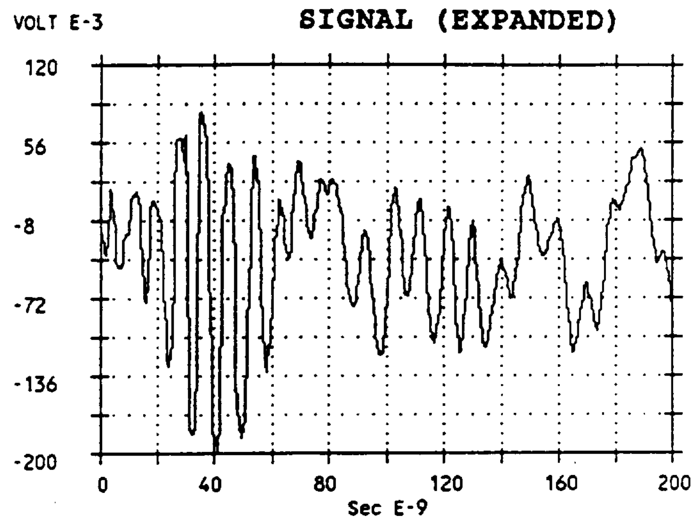
PAGE 1

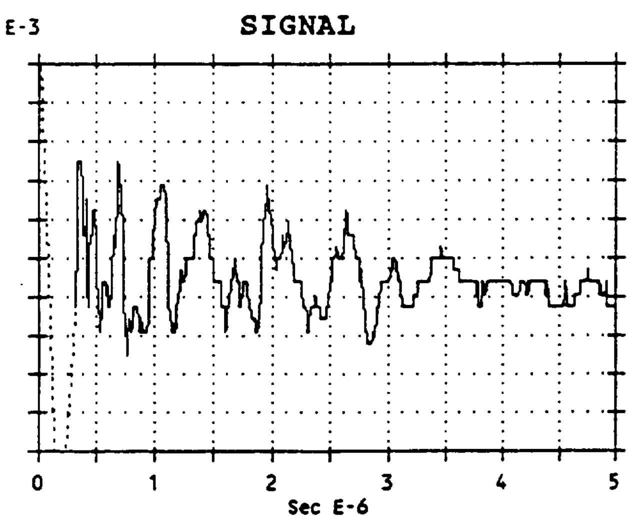
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 11.31073
DOSE RATE: 5.568361E+08
PULSE WIDTH: 20.31 ns
CAL FACTOR: 36325640 rad/volt-sec







FACEPLATE DISTANCE 9" MOVED CABLE FROM RAD PATH & FYK NO LONGER FLOATING

S/N LC-100S-D-PSP-33

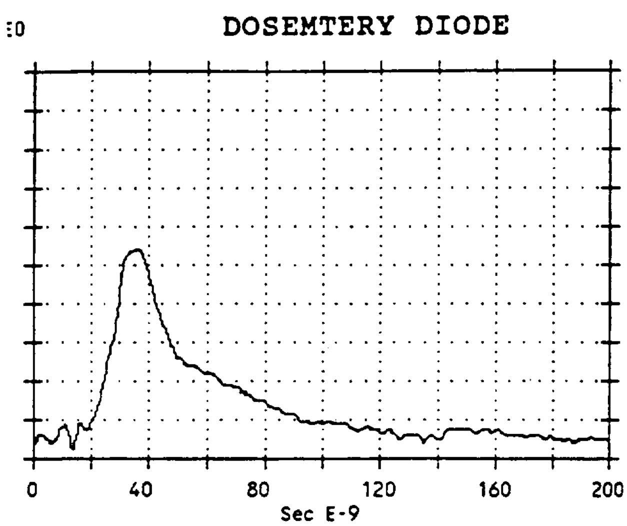
SHOT 10

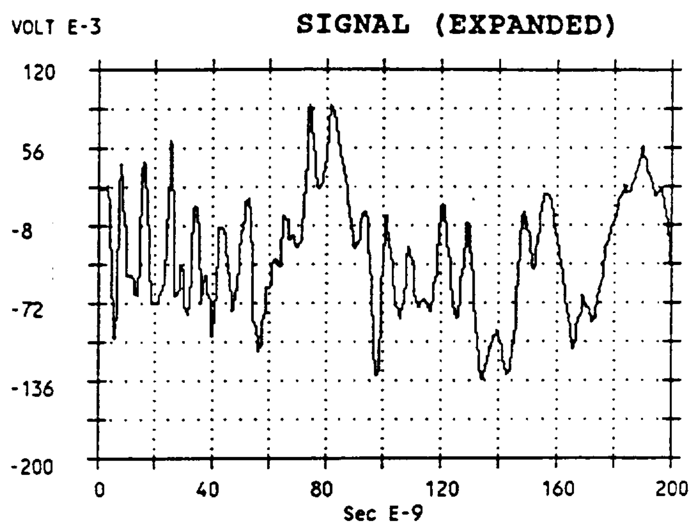
3:02:44 02-01-1994

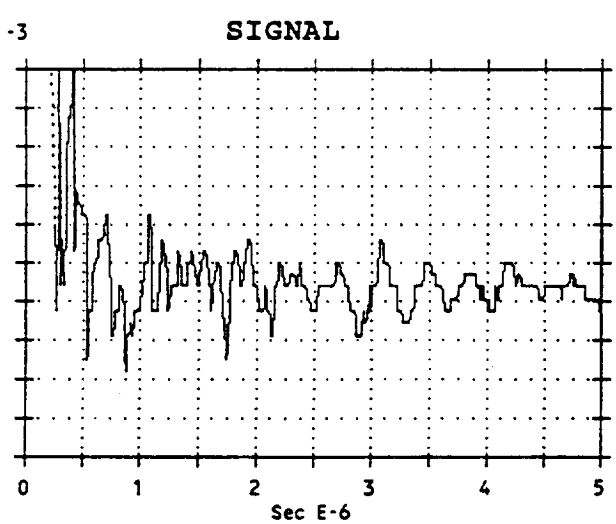
PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE:	FIBER OPTIC FEEDTHRU	DOSE:	10.8651
DEVICE #:		DOSE RATE:	5.248048E+08
MANUFACTURER:	LITECOM	PULSE WIDTH:	20.70 ns
DATE CODE:		CAL FACTOR:	36325640 rad/volt-sec







FACEPLATE DISTANCE 9" FXR FLOATING

S/N LC-100S-D-PSP-33

SHOT ~~10~~ 11

3:06:04 02-01-1994

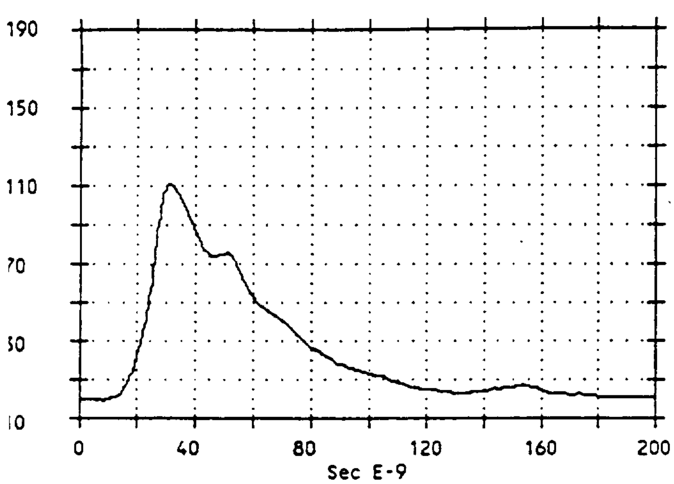
PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

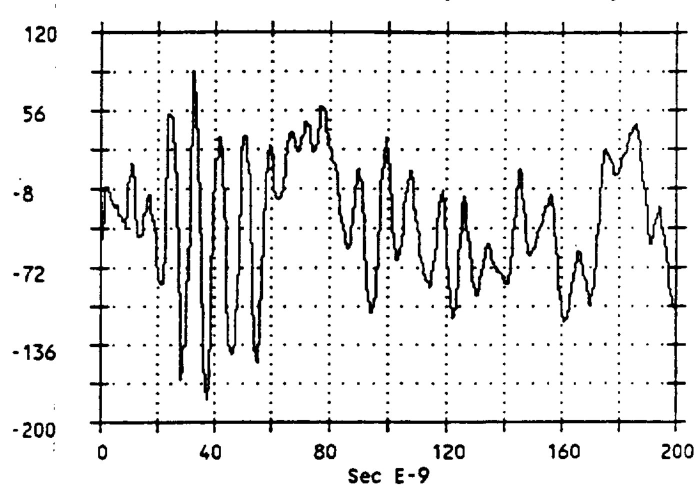
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~159.4678~~ 85.3
DOSE RATE: ~~4.58694E+09~~ 4.47E9
PULSE WIDTH: 34.76 ns
CAL FACTOR: 36325640 rad/volt-sec

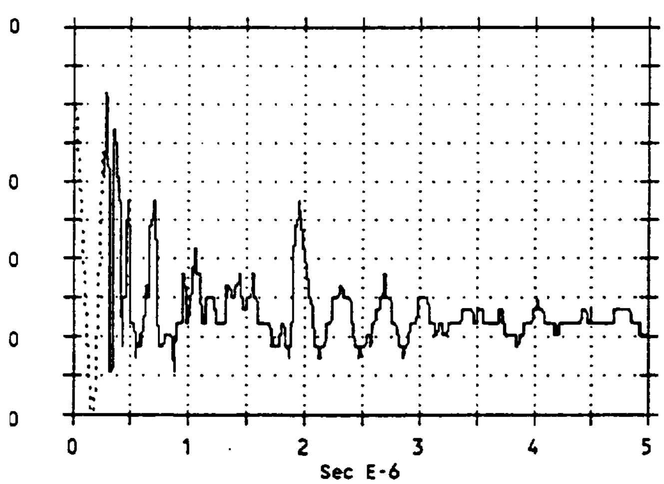
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



DIODE SATURATING ∴ DOSE/DOSERATE INVALID!
FACEPLATE

S/N LC-100S-D-PSP-33

SHOT 13

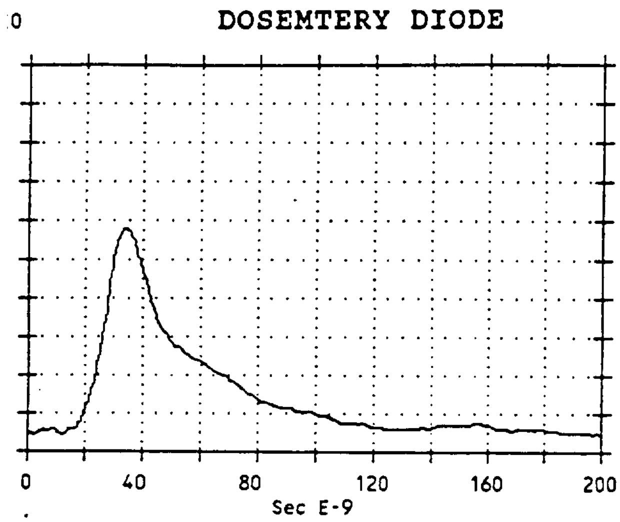
3:22:24 02-01-1994

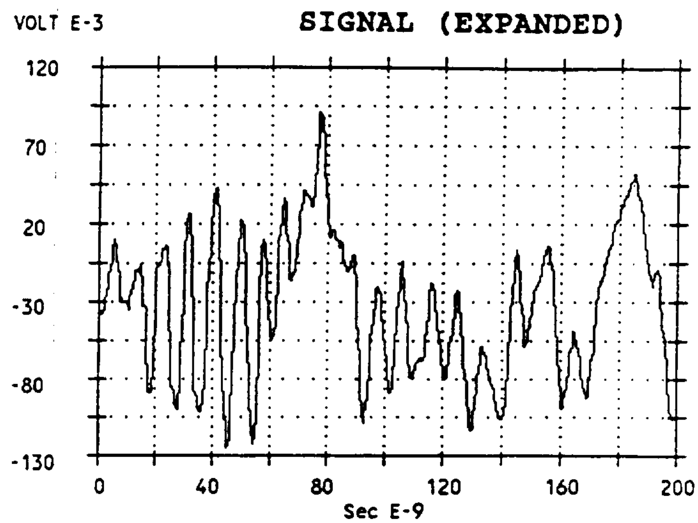
PAGE 1

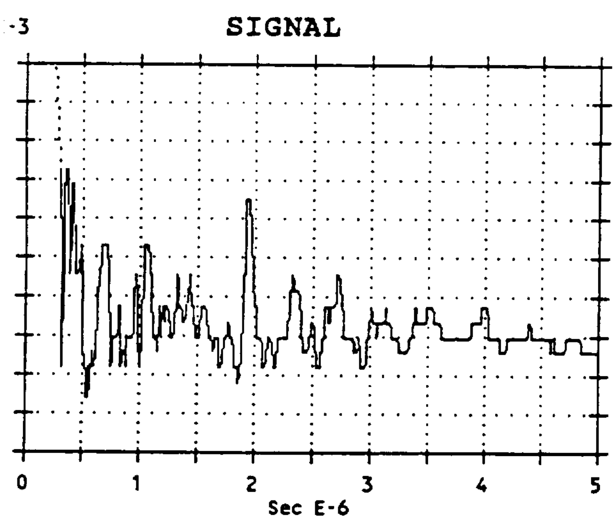
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 23.52387
DOSE RATE: 1.115206E+09
PULSE WIDTH: 21.09 ns
CAL FACTOR: 36325640 rad/volt-sec







FACEPLATE DISTANCE 6"

S/N LC-100S-D-PSP-33

SHOT 12

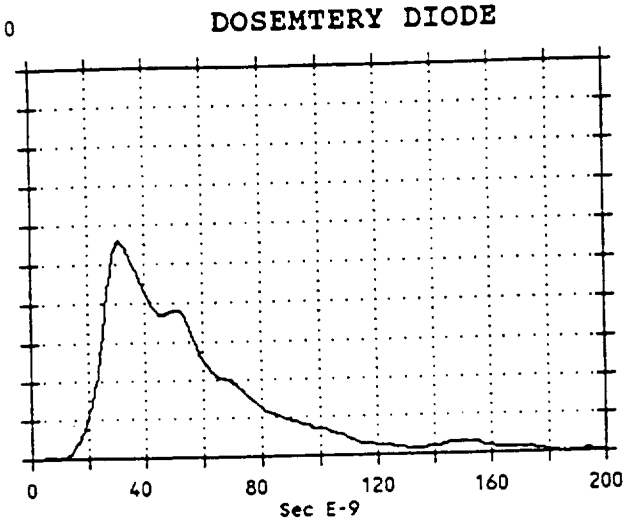
3:12:43 02-01-1994

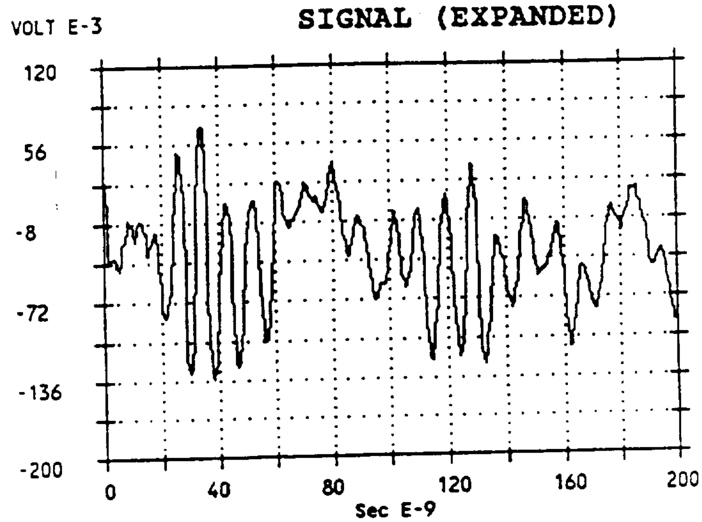
PAGE 1

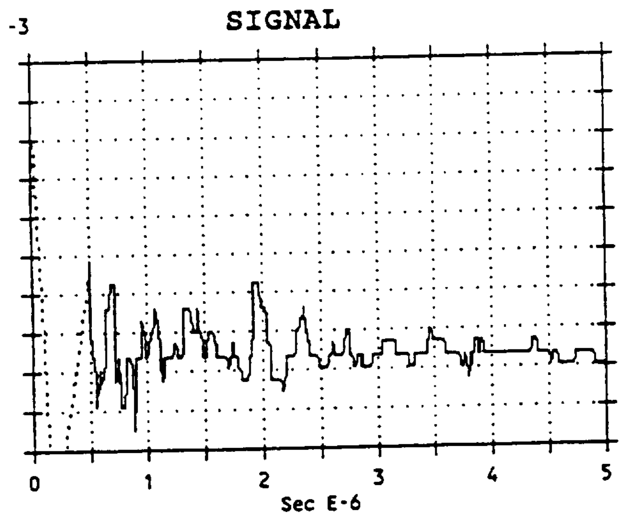
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~4.368287E-06~~ 86.38
DOSE RATE: ~~128.5381~~ 4.55E9
PULSE WIDTH: 33.98 ns
CAL FACTOR: 1 rad/volt-sec







FACEPLATE

S/N LC-100S-D-PSP-33

SHOT 14

PAGE 1

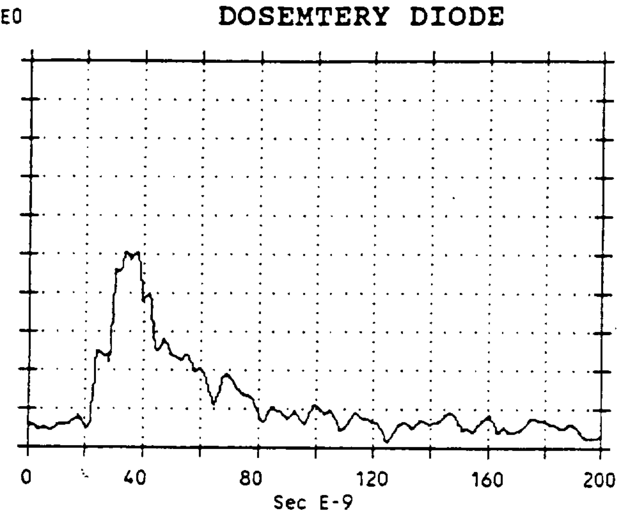
3:30:21

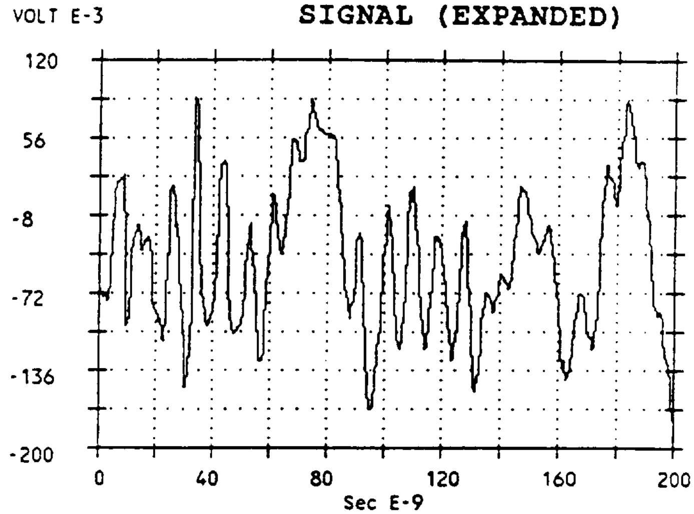
02-01-1994

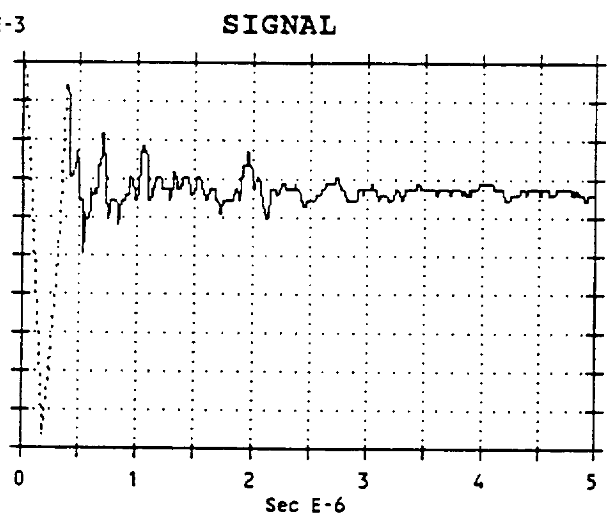
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 3.058846
DOSE RATE: ~~1.957662~~E+08
PULSE WIDTH: 15.62 ns
CAL FACTOR: ~~68699264~~ rad/volt-sec
72937237







23"

S/N LC-100G-D-ALHUGH-39

SHOT 15

3:51:23

02-01-1994

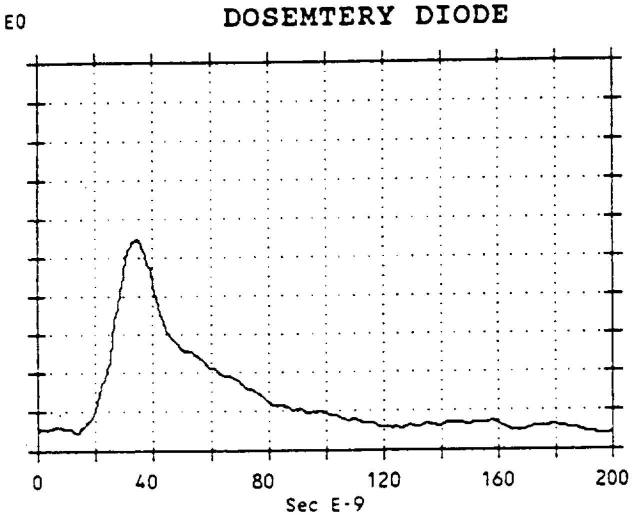
PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

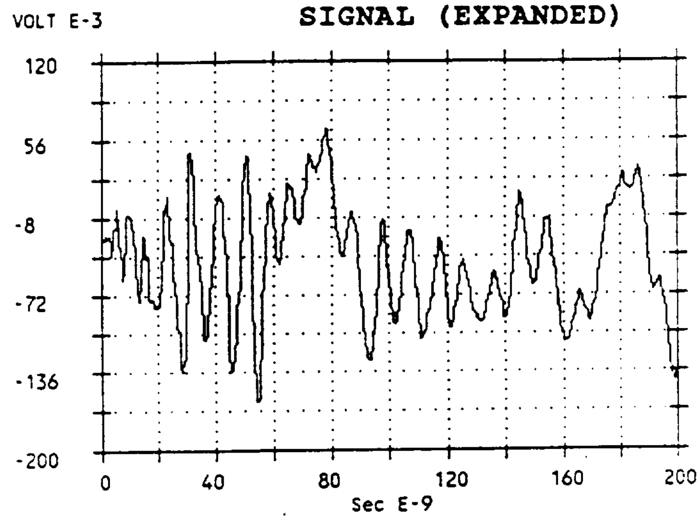
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 10.6099
DOSE RATE: 5.325755E+08
PULSE WIDTH: 19.92 ns
CAL FACTOR: 36325640 rad/volt-sec

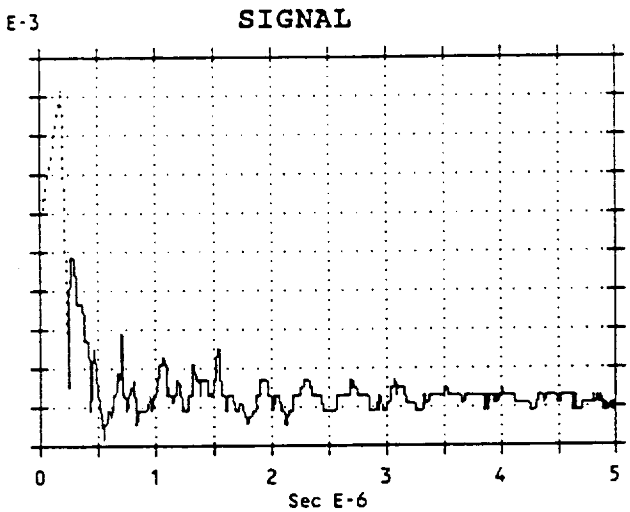
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



9"

S/N LC-100G-D-ALHUGH-39

286

SHOT 16

3:56:48

02-01-1994

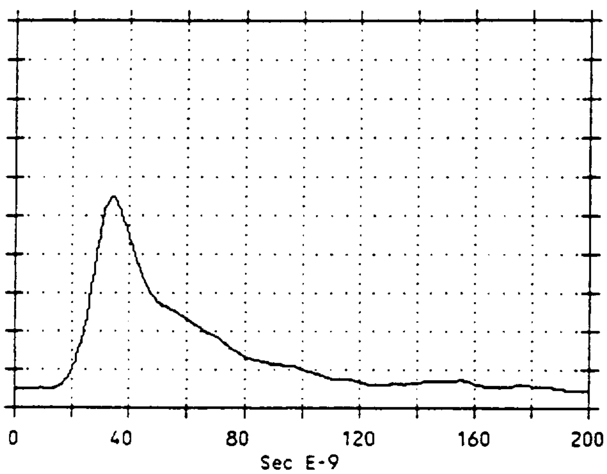
PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

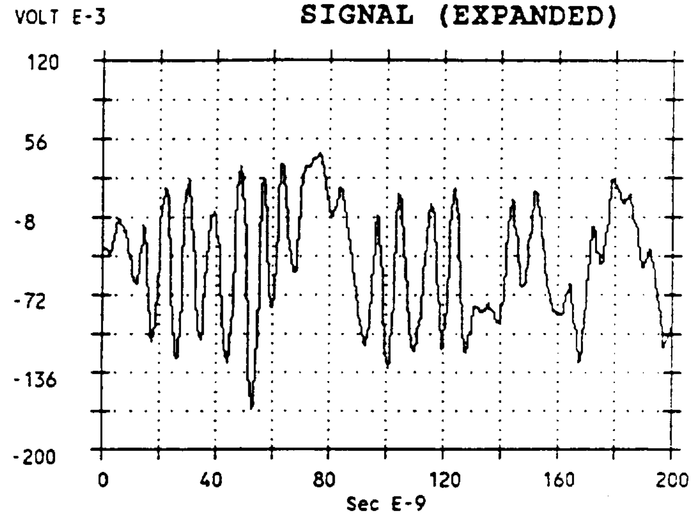
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 22.90417
DOSE RATE: 1.047048E+09
PULSE WIDTH: 21.87 ns
CAL FACTOR: 36325640 rad/volt-sec

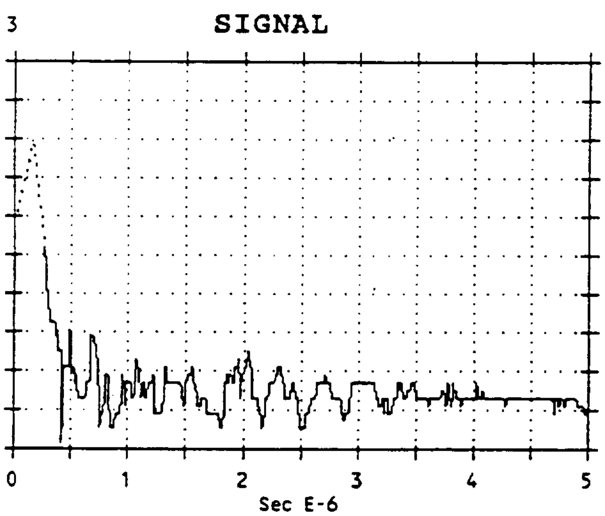
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



6"

S/N LC-100G-D-ALHUGH-39

SHOT 17

3:58:06

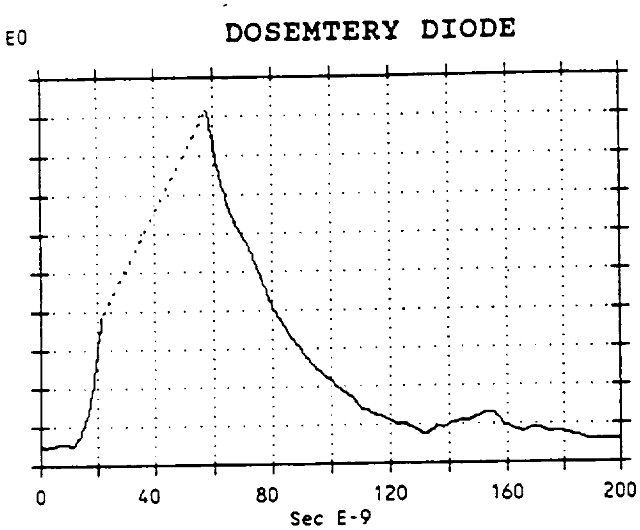
02-01-1994

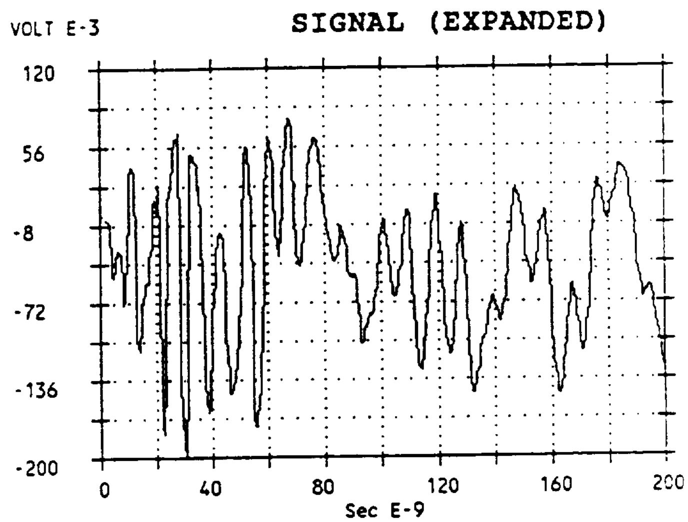
PAGE 1

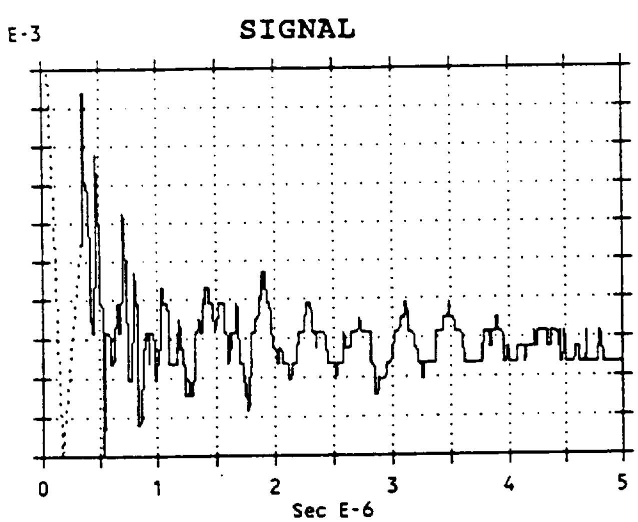
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~1.562073E-~~06 78.14045
DOSE RATE: ~~28.56362~~ 3.74 E9
PULSE WIDTH: 54.68 ns
CAL FACTOR: 1 rad/volt-sec







FACEPLATE

S/N LC-100G-D-ALHUGH-39

SHOT 18

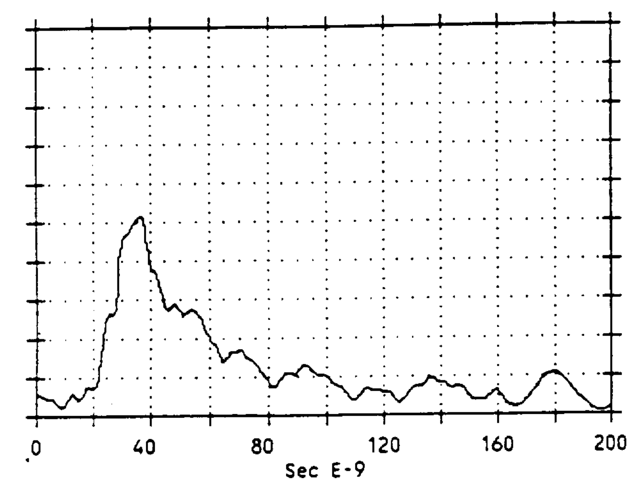
4:00:37

02-01-1994

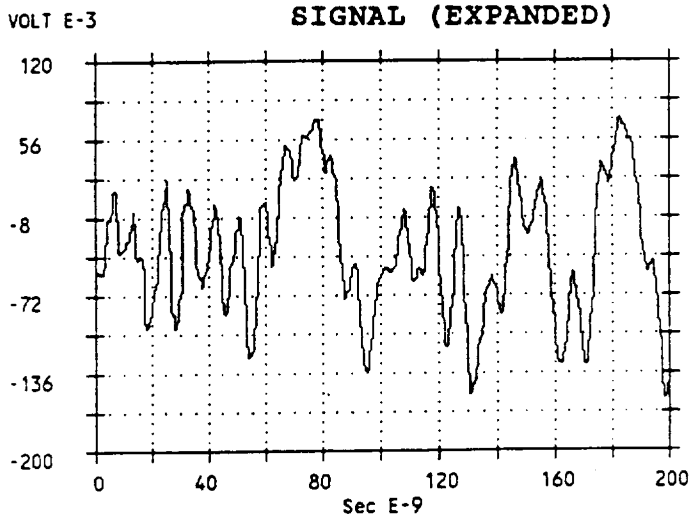
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE:	FIBER OPTIC FEEDTHRU	DOSE:	3.475114
DEVICE #:		DOSE RATE:	~~2.021884~~ 1.26387 E+08
MANUFACTURER:	LITECOM	PULSE WIDTH:	17.18 ns
DATE CODE:		CAL FACTOR:	~~68699264~~ 42937037 rad/volt-sec

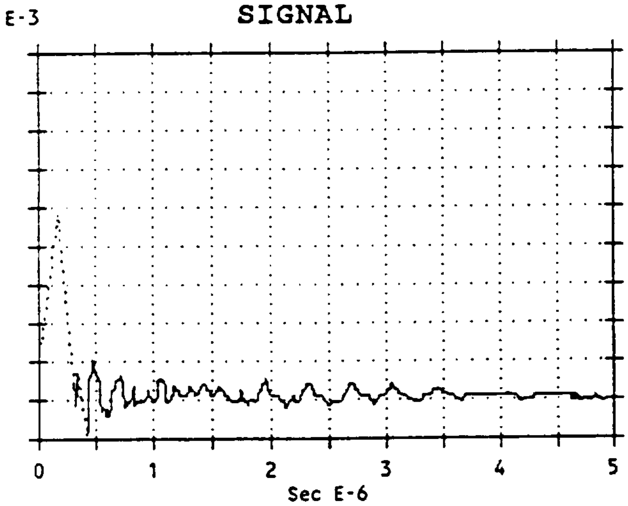
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



23"

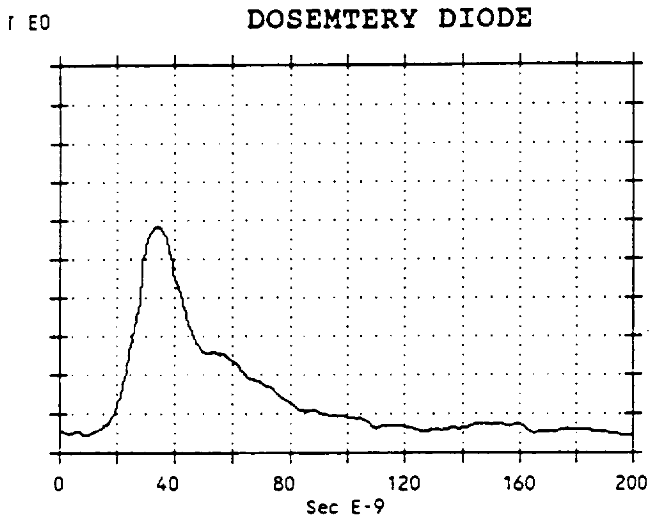
S/N LC-100G-4-GPOLY-38 **289** SHOT ~~20~~ 19

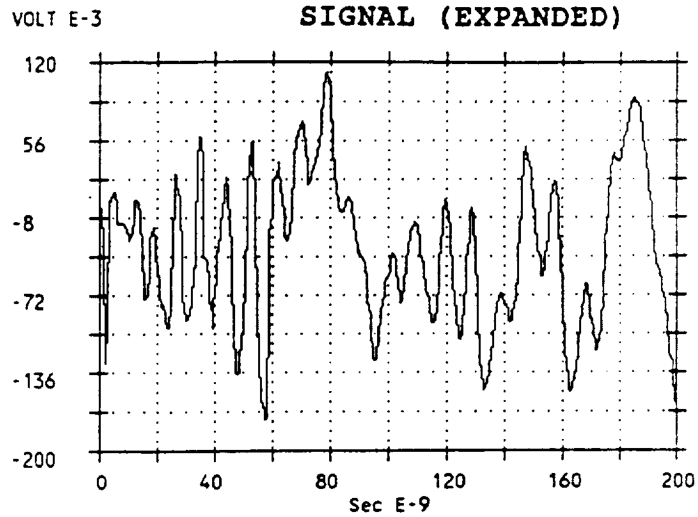
4:10:26 02-01-1994 PAGE 1

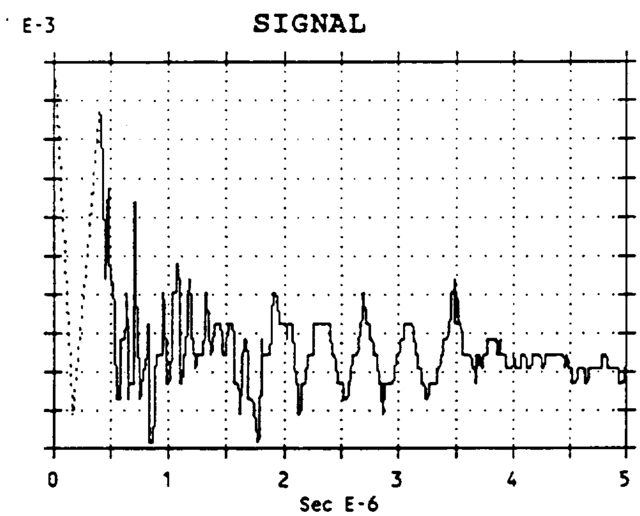
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 11.37416
DOSE RATE: 5.599587E+08
PULSE WIDTH: 20.31 ns
CAL FACTOR: 36325640 rad/volt-sec







9"

S/N LC-100G-4-GPOLY-38

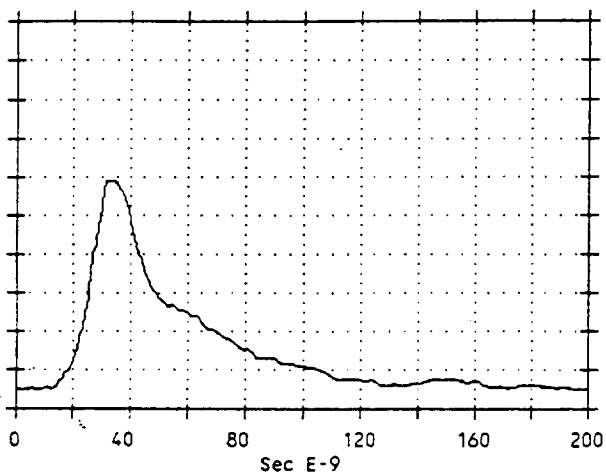
SHOT ~~21~~ 20

4:13:13 02-01-1994

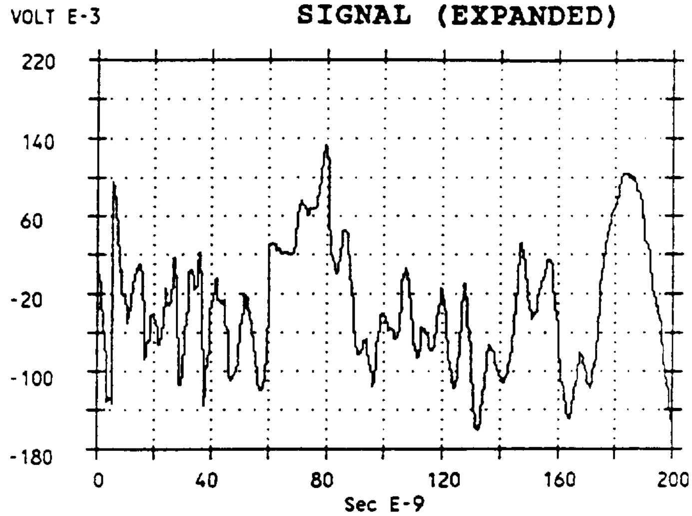
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE:	FIBER OPTIC FEEDTHRU	DOSE:	25.92614
DEVICE #:		DOSE RATE:	1.164402E+09
MANUFACTURER:	LITECOM	PULSE WIDTH:	22.26 ns
DATE CODE:		CAL FACTOR:	36325640 rad/volt-sec

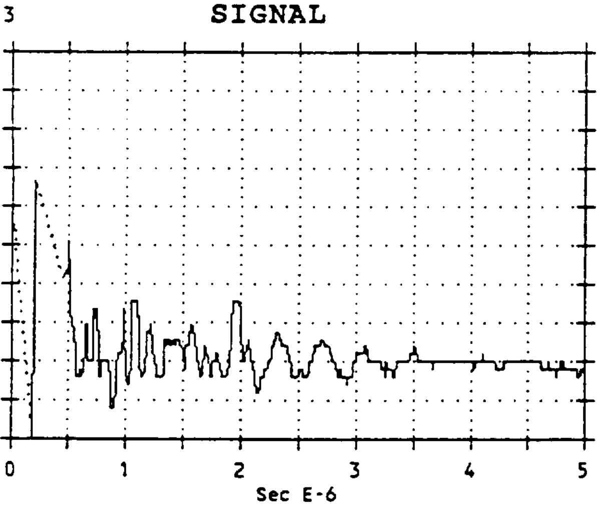
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



6"

S/N LC-100G-4-GPOLY-38

SHOT 21

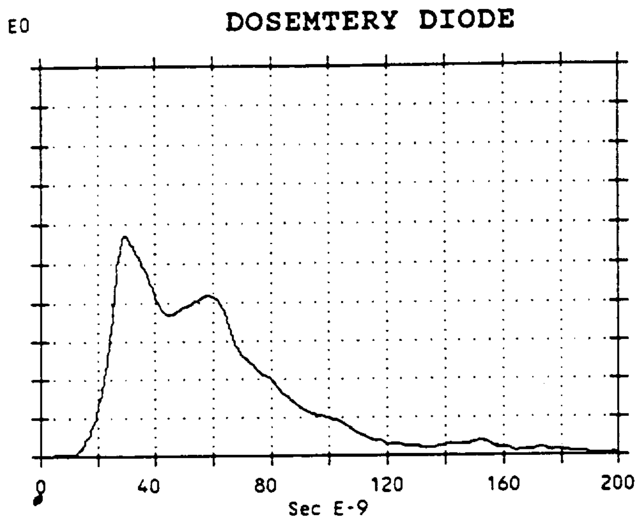
4:14:43 02-01-1994

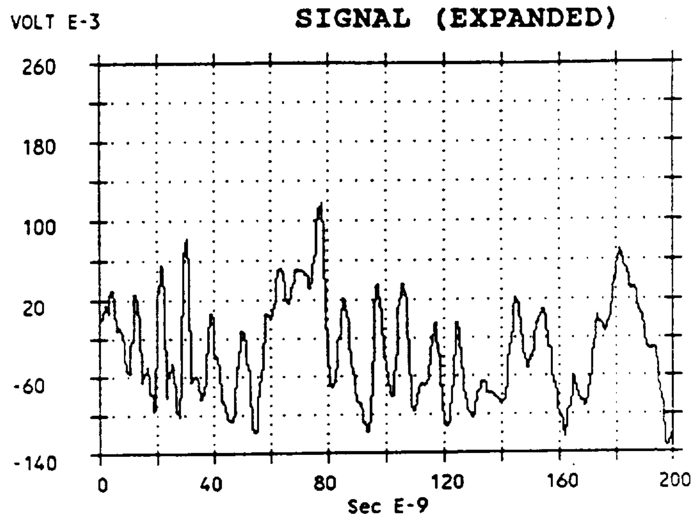
PAGE 1

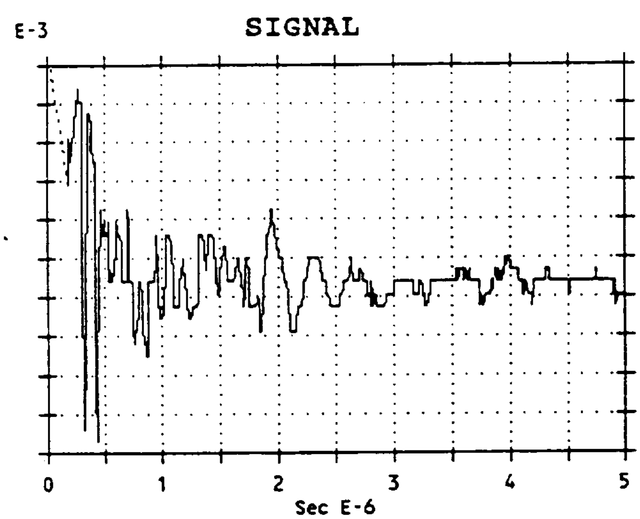
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~5.232117E-06~~ 84.0256
DOSE RATE: ~~117.4932~~ 4.43E9
PULSE WIDTH: 44.53 ns
CAL FACTOR: 1 rad/volt-sec







FACEPLATE

S/N LC-100G-4-GPOLY-38

SHOT 22

4:17:50

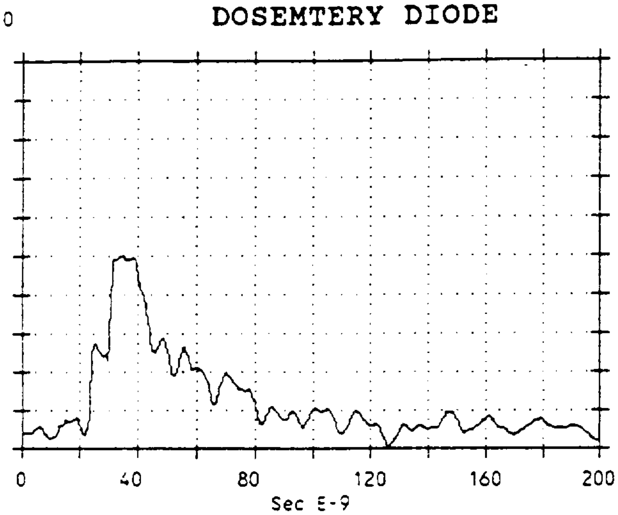
02-01-1994

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

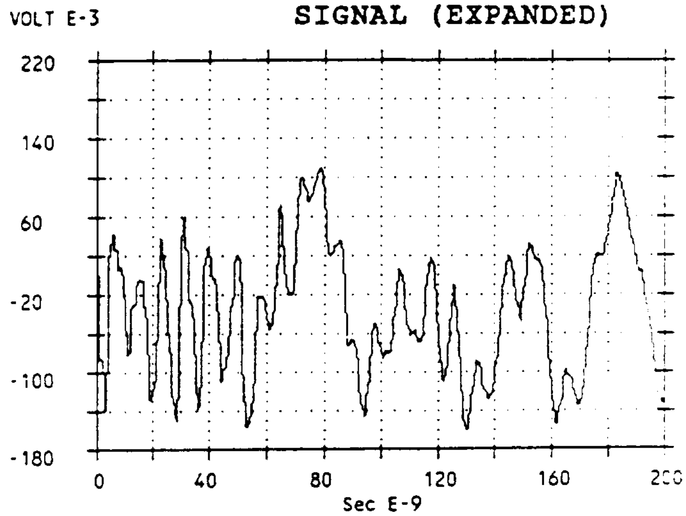
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 3.216505
DOSE RATE: ~~2.166909~~ 1.354112 E+08
PULSE WIDTH: 14.84 ns
CAL FACTOR: ~~68699264~~ 42427037 rad/volt-sec

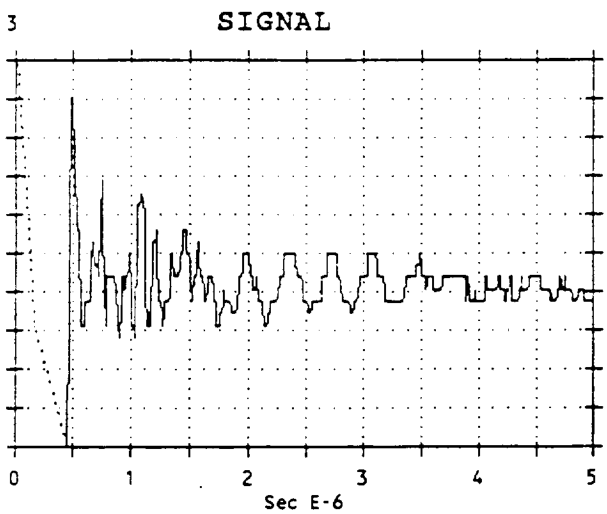
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



23"

S/N LC-100G-4-PSP-33

SHOT ~~24~~23

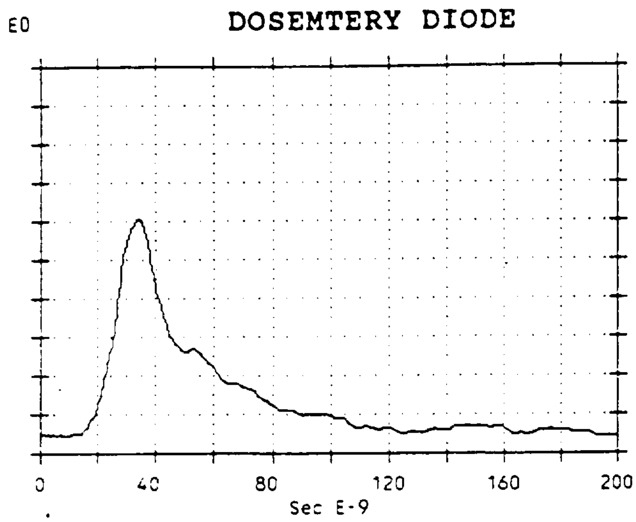
4:33:05 02-01-1994

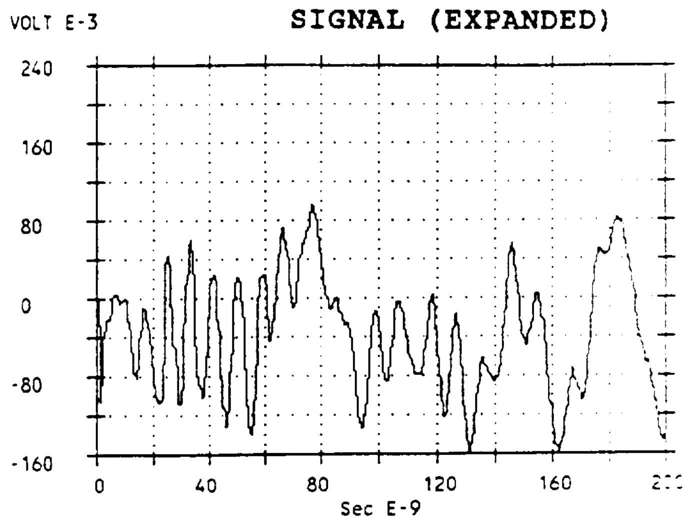
PAGE 1

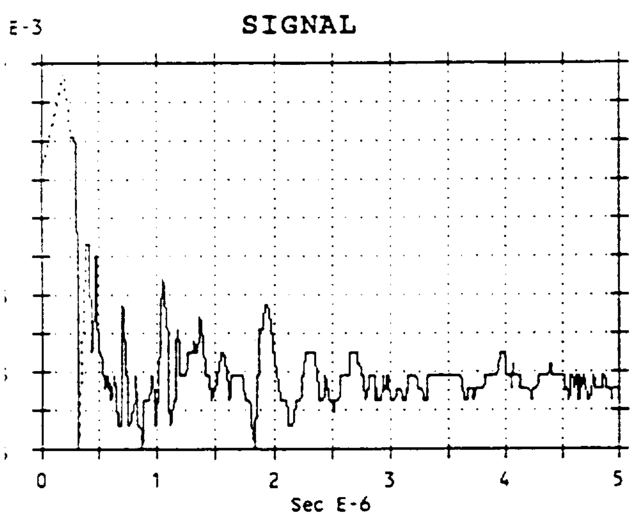
ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 11.11896
DOSE RATE: 6.056287E+08
PULSE WIDTH: 18.35 ns
CAL FACTOR: 36325640 rad/volt-sec







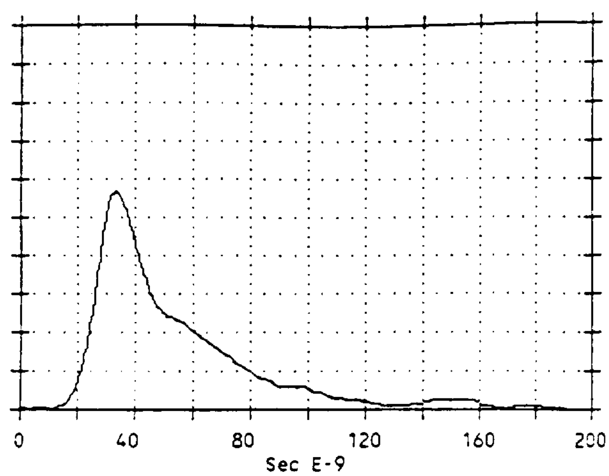
9"

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

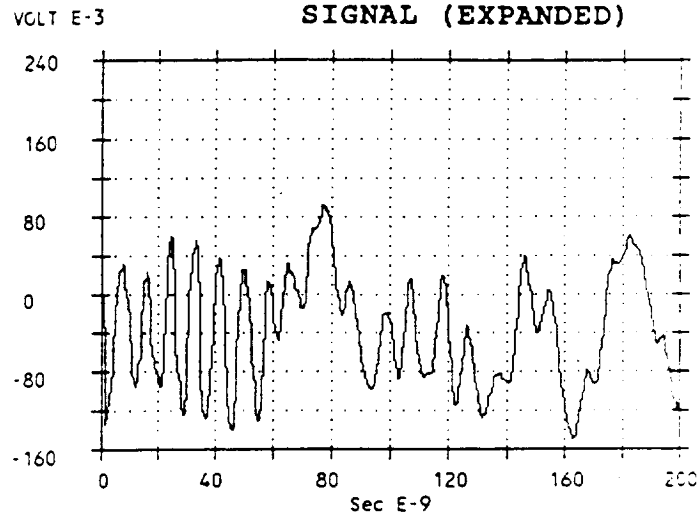
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: 25.63791
DOSE RATE: 1.215427E+09
PULSE WIDTH: 21.09 ns
CAL FACTOR: 36325640 rad/volt-sec

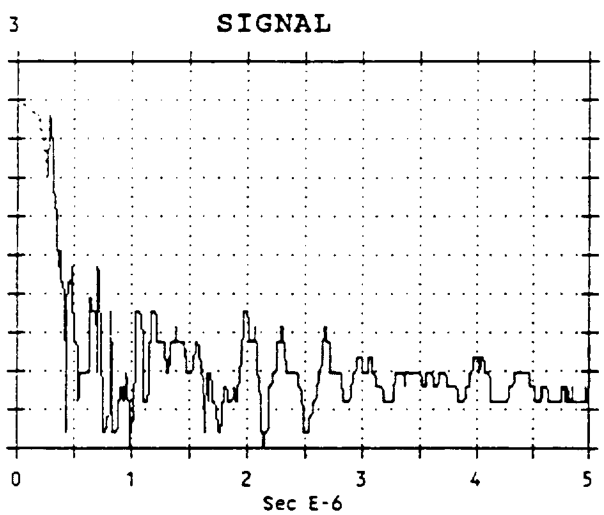
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



6"

S/N LC-100G-4-PSP-33

SHOT 25

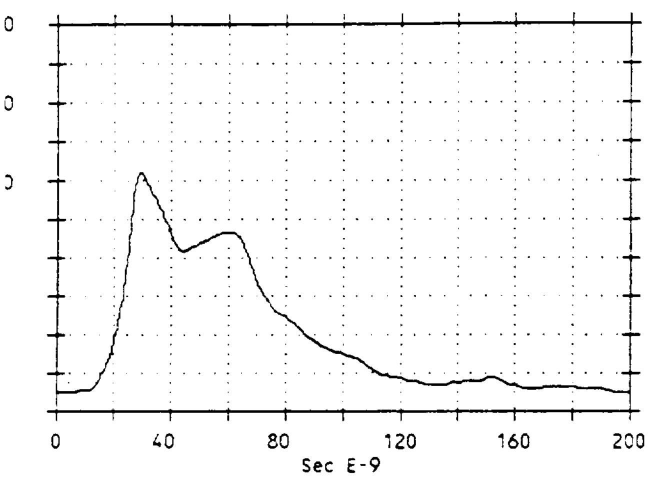
4:37:07 02-01-1994 PAGE 1

ROCKWELL INTERNATIONAL
RADIATION EFFECTS UNIT

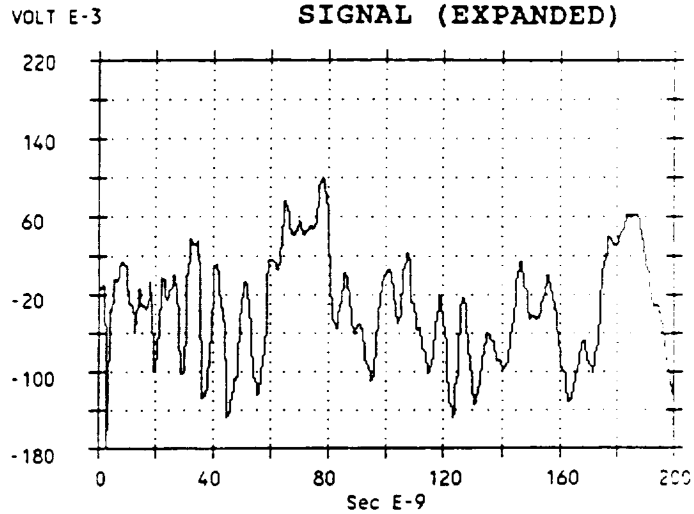
DEVICE TYPE: FIBER OPTIC FEEDTHRU
DEVICE #:
MANUFACTURER: LITECOM
DATE CODE:

DOSE: ~~5.323912E-06~~ 76.00
DOSE RATE: ~~113.5768~~ 4.11E9
PULSE WIDTH: 46.87 ns
CAL FACTOR: 1 rad/volt-sec

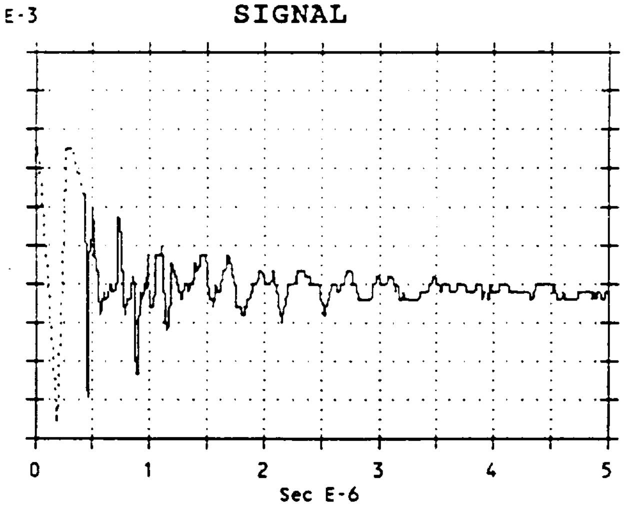
DOSEMTERY DIODE



SIGNAL (EXPANDED)



SIGNAL



FACEPLATE

S/N LC-100G-4-PSP-33

SHOT 26

4:39:47

02-01-1994

PAGE 1

1 - 12.0 Ionizing Dose

The Ionizing Dose radiation testing was conducted on feedthrough units A, B, C, D. Testing was per the test plan, Appendix II of this report, para. 2.7. Test details are described in Appendix VII of this report. Ionizing Dose was the third of the radiation tests conducted.

1 - 12.1 Set-up

Change in optical transmittance was recorded by comparing dBm readings during total ionizing radiation exposure with the initial dBm readings prior to exposure. The exposure time was approx. 30 sec. at 3000 rads (Si), 72 sec. for 10,000 rads (Si), 100 sec. for 20,000 rads (Si), 300 sec. for 50,000 rads (Si) and 500 sec. for 100,000 rads Si. Details of test equipment and set-up are shown in Appendix VII.

1 - 12.2 Data Sheets

The following data sheets record test results. Optical measurements and radiation dose data are included. A photograph of the set-up follows the data sheet.

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: TOTAL IONIZING RADIATION (Rads(Si))
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT 3,000 (Rads(Si)) TOTAL IONIZING RADIATION

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	EXPOSURE TIME (MIN)	RADIATION Rads(Si)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-10.52	-11.14	-11.12	0.52	3,000	0.02
A-B		-11.26	-11.25	0.52	3,000	0.01
B-A		-11.37	-11.40	0.52	3,000	-0.03
C-A		-11.50	-11.44	0.52	3,000	0.06
D-A		-11.65	-11.65	0.52	3,000	0.00
D-B		-11.83	-11.85	0.52	3,000	-0.02
D-C		-11.90	-11.85	0.52	3,000	0.05
D-D		-11.03	-11.00	0.52	3,000	0.03

LIGHT SOURCE: MATH ASSO. #S1850 S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON DATE: FEBRUARY 7, 1994

ENGINEERING ____________ DATE:

ENGINEERING TEST LABORATORY — GENERAL DATA SHEET

TEST: TOTAL IONIZING RADIATION (Rads(Si))

ITEM NAME: FIBER OPTIC FEEDTHROUGH — PART NO. CO27FT

SERIAL NO.: A:LC-100G-D-ALHUGH-39 — SAMPLE NO.

B:LC-100S-D-PSP-33 — PARA NO.

C:LC-100G-4-GPOLY-38

D:LC-100G-4-PSP-33

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT 10,000 (Rads(Si)) TOTAL IONIZING RADIATION

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	EXPOSURE TIME (MIN)	RADIATION Rads(Si)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-10.52	-11.14	-11.11	1.21	10,000	0.03
A-B		-11.26	-11.24	1.21	10,000	0.02
B-A		-11.37	-11.39	1.21	10,000	-0.02
C-A		-11.50	-11.44	1.21	10,000	0.06
D-A		-11.65	-11.69	1.21	10,000	-0.04
D-B		-11.83	-11.86	1.21	10,000	-0.03
D-C		-11.90	-11.85	1.21	10,000	0.05
D-D		-11.03	-11.00	1.21	10,000	0.03

LIGHT SOURCE: MATH ASSO. #S1850 S1850

DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON — DATE: FEBRUARY 7, 1994

ENGINEERING __________ — DATE:

ENGINEERING TEST LABORATORY

GENERAL DATA SHEET

TEST: TOTAL IONIZING RADIATION (Rads(Si))
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-1-GPOLY-38
D:LC-100G-4-PSP-33

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT
20,000 (Rads(Si)) TOTAL IONIZING RADIATION

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	EXPOSURE TIME (MIN)	RADIATION Rads(Si)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-10.52	-11.14	-11.09	1.73	20,000	0.05
A-B		-11.26	-11.22	1.73	20,000	0.01
B-A		-11.37	-11.39	1.73	20,000	-0.02
C-A		-11.50	-11.23	1.73	20,000	0.27
D-A		-11.65	-11.76	1.73	20,000	-0.11
D-B		-11.83	-11.86	1.73	20,000	-0.03
D-C		-11.90	-11.85	1.73	20,000	0.05
D-D		-11.03	-11.01	1.73	20,000	0.02

LIGHT SOURCE: MATH ASSO. #S1850 S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON

DATE: FEBRUARY 7, 1994

ENGINEERING ________________

DATE:

ENGINEERING TEST LABORATORY GENERAL DATA SHEET

TEST: TOTAL IONIZING RADIATION (Rads(Si))
ITEM NAME: FIBER OPTIC FEEDTHROUGH PART NO. CO27FT
SERIAL NO.: A:LC-100G-D-ALHUGH-39 SAMPLE NO.
B:LC-100S-D-PSP-33 PARA NO.
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT
50,000 (Rads(Si)) TOTAL IONIZING RADIATION

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	EXPOSURE TIME (MIN)	RADIATION Rads(Si)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-10.52	-11.14	-11.09	5.19	50,000	0.05
A-B		-11.26	-11.22	5.19	50,000	0.04
B-A		-11.37	-11.30	5.19	50,000	0.07
C-A		-11.50	-11.23	5.19	50,000	0.27
D-A		-11.65	-11.76	5.19	50,000	-0.11
D-B		-11.83	-11.88	5.19	50,000	-0.05
D-C		-11.90	-11.85	5.19	50,000	0.05
D-D		-11.03	-11.02	5.19	50,000	0.01

LIGHT SOURCE: MATH ASSO. #S1850 S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON DATE: FEBRUARY 7, 1994

ENGINEERING __________ DATE:

ENGINEERING TEST LABORATORY — GENERAL DATA SHEET

TEST: TOTAL IONIZING RADIATION (Rads(Si))
ITEM NAME: FIBER OPTIC FEEDTHROUGH
SERIAL NO.: A:LC-100G-D-ALHUGH-39
B:LC-100S-D-PSP-33
C:LC-100G-4-GPOLY-38
D:LC-100G-4-PSP-33

PART NO. CO27FT
SAMPLE NO.
PARA NO.

SPECIFICATION: RADIATION HARDENING TEST LEVEL AT 100,000 (Rads(Si)) TOTAL IONIZING RADIATION

CHAN NO.	MONITOR (dBm)	REFERENCE (dBm)	MEASUREMENT (dBm)	EXPOSURE TIME (MIN)	RADIATION Rads(Si)	CHANGE IN OPTICAL TRANSMITTANCE (dB)
A-A	-10.52	-11.14	-11.09	8.65	100,000	0.05
A-B		-11.26	-11.22	8.65	100,000	0.01
B-A		-11.37	-11.35	8.65	100,000	0.02
C-A		-11.50	-11.30	8.65	100,000	0.20
D-A		-11.65	-11.76	8.65	100,000	-0.11
D-B		-11.83	-11.91	8.65	100,000	-0.08
D-C		-11.90	-11.85	8.65	100,000	0.05
D-D		-11.03	-11.02	8.65	100,000	0.01

LIGHT SOURCE: MATH ASSO. #S1850 S1850
DETECTORS: PHOTODYNE 22XLA; PHOTODYNE 2250XF; AND FOTEC C

TEST BY: ROBERT FAN/JIM NELSON — DATE: FEBRUARY 7, 1991

ENGINEERING ____________ DATE:

1 - 13.0 Final Leak Rate

Feedthroughs were again tested for hermeticity by subjecting them to a pressure differential exposure of 10^{-11} cc/sec helium leak rate.

Leak rate testing was performed by Helium Leak Testing, Inc. of Northridge, CA. The accompanying data sheets indicate leak rate testing after all of the tests. Tests were also conducted after each of the environmental and mechanical tests and the leak rate test was always passed.

1 - 13.1 Data Sheets

Helium Leak Testing, Inc. QHe+

19438 Londelius Street, Northridge, California 91324
(818) 349-5690, (800) 423-1701, FAX (818) 717-8584

DATE: 1-27-94

TO: Litecom Inc.
8033 Remmet Ave.
Canoga Park, CA 91304

ORDER NO.
HLT JOB NO. 28042

DESCRIPTION: 6 - (Accepted) Fiber Optic Feed Thru, P/N's LC-100S-D-PSP-32, LC-100G-4-ALHUGH-37, LC-100G-4-GPOLY-38, LC-100G-D-38, LC-100G-DACHUGH-39, LC-100S-D-PSP-33

The test was performed with an Alcatel Mass Spectrometer Helium Leak Detector M/N ASM-110TCL, S/N 1298, in accordance with HLT QCM, Rev. 6.

The Leak Detector was calibrated with a Veeco Calibrated Leak S/N 1060.

The sensitivity of the instrument was such to detect a leak greater than or equal to 2.0 X 10^{-11} cc/sec. of helium, with an external pressure of one atmosphere.

No leakage was indicated with machine capability of 2.0 X 10^{-11} cc/sec. helium.

G.R. Markel

G.R. Markel
NDT Level III Examiner (LT)

LEAK TEST APPROVED 33

CERTIFICATION

Helium Leak Testing, Inc.

19438 Londelius Street, Northridge, California 91324
(818) 349-5690, (800) 423-1701, FAX (818) 717-8584

: Litecom Inc.
8033 Remmet Ave.
Canoga Park, CA 91304

DATE: 3-11-94

ORDER NO. LC940310
HLT JOB NO. 28364

SCRIPTION: 1 - (Accepted) P/N LC-100G-4-PSP-36 Fiber Optic Feedthrough.
1 - (Accepted) P/N LC-100G-4-PSP-33 Fiber Optic Feedthrough.

The test was performed with an Alcatel Mass Spectrometer Helium Leak Detector Model ASM-10, S/N 2010, in accordance with HLT QCM, Rev.0.

The Leak Detector was calibrated with a Veeco Calibrated Leak S/N 1060.

The sensitivity of the instrument was such to detect a leak greater than or equal to 2 X 10^{-11} cc/sec. of helium, with an external pressure of one atmosphere.

No leakage was indicated with machine capability of 2 X 10^{-11} cc/sec. helium.

G.R. Markel

G.R. Markel
NDT Level III Examiner (LT)

LEAK TEST APPROVED 33

CERTIFICATION

APPENDIX 5

Helium Leak Testing Specification

1.0 PURPOSE. This document defines a uniform procedure for helium leak testing of vacuum penetrators.

2.0 SCOPE. All vacuum penetrators shall be helium leak tested in accordan with this specification.

3.0 EQUIPMENT.

3.1 Helium mass spectrometer leak detector (MSLD).
3.2 Test chamber(s) and manifold.
3.3 Roughing pump(s).

4.0 PREPARATION. All assemblies to be tested shall be baked at 150F for two hours minimum prior to test.

5.0 TEST PROCEDURE. This procedure, although written for one test chamber, is applicable to multiple test chambers provided adequate manifolding is employed.

5.1 Close MSLD and pump valves.
5.2 Mount assembly to be tested into an appropriate flange. Mount into a test chamber.
5.3 Start the roughing pump, open the pump valve, and record the time on the helium leak test data sheet.
5.4 After one minute per foot of overall assembly length, proceed as follows:

5.4.1 Calibrate and zero MSLD.
5.4.2 Record time on data sheet.
5.4.3 Close pump valve.
5.4.4 Open MSLD valve.
5.4.5 Test background.

5.4.5.1 If background is less than 1×10^{-9}, record on data sheet and proceed to 5.6.
5.4.5.2 If background is greater than 1×10^{-9}, but is less than allowable leak for penetrator, proceed to 5.5.
5.4.5.3 If background is greater than allowable leak for penetrator, record on data sheet and reject penetrator.

5.5 Close MSLD valve, open pump valve. Repump for one minute per foot of overall assembly length. Close pump valve, open MSLD valve, and retest background.

5.5.1 If background is unchanged from previous reading, record on data sheet and proceed to 5.6.
5.5.2 If backgroundis reducing return to 5.5. Continue until background is less than 10^{-9} or is stable. Record on data sheet and proceed to 5.6.

5.6 Close MSLD valve.

5.7 Bag penetrator assembly and fill with helium. Refill as required during test.

5.8 Recalibrate and rezero MSLD.

5.9 Open MSLD valve and record time on data sheet as leak test start.

- 5.9.1 Record leak after 5 minutes.
- 5.9.2 Record leak after 10 minutes.
- 5.9.3 Record final leak after one minute per foot of overall assembly length.

6.0 ACCEPTANCE/ REJECTION CRITERIA.

- 6.1 Accept penetrator if (5-minute leak)-(background) is less than or equal to allowable leak for penetrator.
- 6.2 Reject penetrator if (5-minute leak)-(background) is less than allowable leak for penetrator.

7.0 DATA SHEET APPROVAL. All data sheets shall be reviewed and approved by the Quality Control Manager or his designated alternate prior to release for shipment. Such approval shall constitute technical verification of the acceptance/rejection decision.

8.0 DESIGNATED ALTERNATE. The designated alternate to the Quality Control Manager shall be an engineer in the design group.

9.0 DATA SHEET. A facsimile data sheet is attached to this specification as page 5.

10.0 RECORDS RETENTION. One copy of each data sheet shall be maintained on file by the Quality Control Department for a period of one year following the date of test.

LITECOM, INC.

Helium Leak Test Data Sheet

MO____________________ Customer____________________

DE____________________ Rev____________________

Overall Length __________ Allowable Leak__________

Roughing Pump Start__________

Background Test Start__________

Background Level____________________

Helium Leak Test Start__________

5 Minute Leak ____________________

10 Minute Leak ____________________

Helium Leak Test Finish__________

Final Leak____________________

Accept______

Reject______

Test Performed by____________________Date__________

Test Review by____________________Date__________
QC Manager

Designation: E 479 – 73 (Reapproved 1984)[ε1]

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa. 19103

Standard Guide for PREPARATION OF A LEAK TESTING SPECIFICATION[1]

This standard is issued under the fixed designation E 479; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

[ε1] NOTE—Editorial changes were made throughout in April 1984.

1. Scope

1.1 This standard is intended as a guide. It enumerates factors to be considered in preparing a definitive specification for maximum permissible gas leakage of a component, device, or system. The guide relates and provides examples of data for the preparation of leak testing specifications. It is primarily applicable for use in specifying halogen leak testing methods.

1.2 Two types of specifications are described:

1.2.1 Operational specifications (OS), and

1.2.2 Testing specifications (TS):

1.2.2.1 Total, and

1.2.2.2 Each leak.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Applicable Documents

2.1 *ASTM Standards:*

E 425 Definitions of Terms Relating to Leak Testing[2]

E 427 Practice for Testing for Leaks Using the Halogen Leak Detector (Alkali-Ion Diode)[2]

E 432 Guide for the Selection of a Leak Testing Method[2]

3. Definitions

3.1 *operational specification (OS)*—a specification from which the others are derived. The specification specifies and states the limits of the leakage rate of the fluid to be used for the product using criteria such as failure to operate, safety, or appearance.

3.2 *testing specification (TS)*—a specification for the detection, location, or measurement, or a combination thereof, of leakage. The operational fluid usually is not detectable with commercially available leak detectors. The leak test must be performed with a suitable test gas containing a tracer to which the detector is sensitive. The pressure magnitude and pressure direction may vary greatly from operational conditions. These and other factors are to be considered and evaluated when the leak testing performed to the requirements of the TS is to result in a product that meets most of the OS requirements. In addition, should a product be tested with a detector or tracer probe from point to point, allowance should be made for the possibility of two or more leaks, each causing less leakage than the total leakage maximum, but adding up to an amount greater than allowed.

4. Specification Content and Units

4.1 The content and units of the specification should relate the following data:

4.1.1 Mass flow per unit of time, preferably in Pascal cubic metres per second ($Pa \cdot m^3/s$).

4.1.2 The pressure differential across the two sides of possible leaks, and the direction, in pounds per square inch (psi) or metric units (Pa).

4.1.3 Any special restrictions or statement of facts that might prohibit the use of a particular

[1] This guide is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E 07.08 on Leak Testing.

Current edition approved May 28, 1973. Published July 1973.

[2] *Annual Book of ASTM Standards*, Vol 03.03.

type of leak testing method.

4.1.4 The methods of the leakage specification shall not be limited to any one particular method unless it is the only one suitable. Specific leak testing methods can be selected when careful consideration of the facts is outlined (refer to Guide E 432 or the other applicable documents of Section 2).

5. Significance and Use

5.1 For any product to be tested the geometrical complexity will vary widely. However, the basic concept of determining an operative leakage specification regardless of geometries is much the same for all, whether it be simple, ordinary, or complex.

5.2 The data required for writing the OS, which is total leakage ($Pa \cdot m^3$), time (s), and pressure difference across the leak, are either available or can be determined by tests or measurements.

5.3. A user who selects values to be used in a leakage specification as a result of someone else having used the value or simply because of prestige reasons, may find the value or values unsatisfactory for the product.

5.4 A specification that is too restrictive may result in excessive leak testing costs.

5.5 A typical illustration for determining a leakage specification, using the complex geometry of a refrigerant system for an example, will be used throughout this recommended guide. It is well to point out that the user should realize that the values and test methods selected do not necessarily represent the best or typical ones for this application.

6. Procedure

6.1 The example that follows is to be construed as applicable to the equipment and testing method cited, and is not to be construed as setting up mandatory leakage rates for any other equipment or method of testing. The example used to illustrate the use of this guide is as follows: An automotive air-conditioning system using Refrigerant-12 (R-12, dichlorodifluoromethane) and consisting of a compressor, condensing coil, thermostatic expansion valve, evaporating coil, vacuum-operated hot gas bypass capacity control valve, and a sealed temperature control thermostat.

6.2 *OS, Refrigerant Circuit*—It is desirable that the rechargeable portions of the system operate three years before requiring additional refrigerant; for the sealed parts, 5 years. Tests show that 6 oz of the normal charge can be lost before serious operational inefficiency begins, and the neoprene connecting hoses have a basic permeation rate of 1 oz/year. Inspection of the system shows that the vacuum operator of the capacity valve and the thermostat are not directly connected to the refrigerant circuit, and can thus be considered separately.

6.2.1 *Calculations:*

Leakage to be detected = 6 oz (total loss) − 1 oz × 3 years = 3 oz

Period = 3 years

Rate = 3 oz/3 years = 1 oz/year. Rate (standard units) = 1 oz/year × 1.8×10^{-4} (or 0.00018 = R-12 conversion factor) = 1.8×10^{-5} $Pa \cdot m^3/s$. See 6.6.3

Pressure—The maximum operating temperature of the system will be 77°C at which temperature the pressure of the refrigerant will be about 2.07 MPa. Pressure difference = 2.07 MPa (internal) − 0.10 MPa (atmosphere) = 1.97 MPa.

6.2.2 Therefore, the following would appear on the appropriate documents: Leakage Specification (Operational): 3.6×10^{-5} MPa max at 1.97 MPa pressure difference (1.8×10^{-5} $Pa \cdot m^3/s$ excluding hose permeation).

6.3 *TS, Refrigerant Circuit:*

6.3.1 For a unit to be tested at the OS level, any inaccuracies in the test could cause possible unit acceptance when in fact the unit may leak in excess of the amount allowed. Most testing conditions cannot duplicate operating conditions. Should a point-by-point probing technique be used, a number of smaller leaks may allow a total leakage in excess of the value specified.

6.3.2 In addition, some portions of the system may be purchased as a completed operative component. Their potential contribution to the total system leakage must be limited. It is because of the requirements of the testing specification that these and other factors are considered, and that required leak testing at levels to ensure acceptable quality levels in the final product is made with the consideration for a lesser testing cost. Often it is necessary to divide the leakage allowance equitably among various components, taking into account the statistical probability of the largest allowable leakage occurring in a number of a given set of components.

6.3.2.1 *Division of Leakage Allowance Among System Components*—Assume in the previous example that the compressor, condensing and evaporating coils, the expansion valve, capacity control valve, and sealed thermostat all have to be considered. Also assume that the compressor and evaporating coil will both be tested separately before assembly into the system, as each has a number of fabricated joints more prone to leakage than the condensing coil. The condensing coil, considered a continuous length of tubing, can be tested at the final system test. All components except the thermostat make up some portion of the refrigerant circuit. How then should the leakage allowance be divided among them? The usually equitable way is to make the division on the basis of the number of joints in each, considering 25 mm of seam as one "joint." A tabulation example on this basis follows:

	No. of Joints	% of Total
Compressor	36	28
Condensing coil	78	60
Expansion	7	5
Capacity control valve	9	7
Total	130	100

6.4 *Factor of Safety for Leak Testing Accuracy*—When establishing the data for the factor of safety for leak testing accuracy and when performed by various people using different equipment, facilities, or operating standards, the resulting data usually will vary tremendously. Results of a round-robin test conducted by ASTM resulted in a spread of the test data of about one decade. This value is considered valid for leak tests using procedures and equipment described in Section 2. Therefore any operational specification may apply a factor of ⅓ or 0.3.

6.5 *Factor of Safety for Number of Leaks per System*—When a unit or device has a number of points that may leak, the leak test is to be performed by point-to-point probing. There is a possibility that the sum of all leaks smaller than the specification total may add up to an amount in excess of it. However, this is dependent upon the number of leak possibilities or on whether there is any distortion of the normal leak distribution curve, which covers many decades of sizes. The factor assigned here may depend upon a judgment of the probability of such an event occurring, the degree of confidence needed in the leak test, and the safety factor that can be afforded. In this example, assume that the condensing coil is of welded aluminum which has a strong tendency to have porosities that leak in the range of 10^{-6} Pa·m³/s. For this reason, the TS total will be divided by five for this item, and by three for the others, that is, a factor of 0.2 and 0.3 respectively.

6.6 *Factor of Safety for Test versus Operating Conditions:*

6.6.1 *Pressure*—As a recommendation, the leakage is assumed to be proportional to the difference of the squares of the pressures on each side of the leak. However, for this example, it is assumed that a 2.76 MPa pressure difference, high pressure internal, is needed. This would allow combining the leak test with the burst test which is fixed at 2.86 MPa, absolute internal − 0.10 MPa, absolute external = 2.76 MPa. This pressure will possibly reveal leaks that can only develop with higher stress. With the operating condition at 2.07 MPa, gage max, greater leakage can be expected at the higher test pressure. Calculate the Factor of Safety as follows:

$$\text{Factor of Safety} = (P_2^2 - P_1^2)/(P_3^2 - P_1^2) = (2.76^2 - 0.1^2)/(2.07^2 - 0.1^2) = 1.8$$

where:

P_1 = pressure, atmospheric,
P_2 = high pressure (internal), and
P_3 = pressure, operating.

Therefore, a factor of 1.8 can be applied to the operational specification.

6.6.2 *Test Gas*—Except at high ambient temperatures, most refrigerant gases normally used in a system will liquefy before the test pressure is reached. Nonetheless, other gases or mixture of gases, will be required for leak testing. The more suitable gases, such as helium, nitrogen, air, etc., have a viscosity of about 1.9×10^{-4} P, compared to 1.2×10^{-4} for most halogenated refrigerants, compared to 1×10^{0} for water and 1×10^{2} for lubricating oils. The leakage of a fluid is inversely proportional to its viscosity. Therefore, the correction for test fluid is extremely important, particularly when liquids are involved. In this example a factor of 1.2×10^{-4} divided by $1.9 \times 10^{-4} = 0.6$ will be used.

6.6.3 *Test Specifications*—From an operational specification of 1.8×10^{-5} Pa·m³/s. (excluding hoses) the testing specification for the completed system is derived (Note Appendix Table X1, Nos. 1–4). Test specification, total = $1.8 \times 10^{-5} \times 0.3$ (equipment accuracy) × 1.8 (gas pressure) × 0.6 (gas viscosity) = $1.8 \times 10^{-5} \times 0.32 = 5.8 \times 10^{-6}$. Round the coefficient to the nearest whole number. The total for all leaks will be: "Leakage specification, testing, total: 6×10^{-6} $Pa \cdot m^3/s$, max at 2.76 MPa pressure differential, pressure internal." Therefore, each leak = $6 \times 10^{-6} \times 0.3$ (selected by consideration of 6.5) = 1.8×10^{-6} $Pa \cdot m^3/s$. Rounded, each leak will be: "Leakage specification, testing, each leak: 2×10^{-6} $Pa \cdot m^3/s$ at 2.76 MPa pressure differential, pressure internal."

6.6.4 *Testing Specification, Purchased Components*—When purchased components will be subject to receiving inspection for compliance with the leakage specification supplied to the vendor, these two specifications should not be the same; otherwise, parts tested at normal accuracies by the vendor may be rejected by the customer. Therefore, a typical factor of about $^1/_{10}$ (0.1) should be applied to the vendor's specification.

6.6.4.1 *Expansion Valve*—This component has two leakage requirements. The part common with the refrigerant system must meet its requirements; the sealed operator assembly, a diaphragm, capillary tube, and bulb filled with R-12 gas has its own operation specification.

Refrigerant System Side Specifications: Test Specification, Total—In the tabulation example in 6.3.2.1 an allowance of 5 % for the expansion valve compartment was established. Applying this to the similar system specification: $1.8 \times 10^{-5} \times 0.05 = 9 \times 10^{-7}$ $Pa \cdot m^3/s$. (This allowance might be increased on a statistical basis if desired.) Thus the specification for this component can be tabulated as follows:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal (Note Appendix Table X1, Nos. 5–8)

Type of Specification	Seller	User	Maximum Leakage, $Pa \cdot m^3/s$
Testing, total		X	9×10^{-7}
Testing, total	X		9×10^{-8}
Testing, each leak		X	3×10^{-7}
Testing, each leak	X		3×10^{-8}

Observe that a factor of $^1/_3$ has been applied for probe testing versus total leakage testing.

Operator Assembly Specifications—This is an independent system, and the operational specification must be established as before. Make the following calculations:

Maximum loss of R-12 before malfunction:	2 standard cm^3
Time limit:	5 years
Pressure (internal)	0.6 MPa

Operational specification
$= 2/(5 \times 3.15 \times 10^7) = 1.3 \times 10^{-8}$ $Pa \cdot m^3/s$

Using factors previously discussed, the specifications may be tabulated as follows:

Maximum Leakage at 0.48 MPa Differential, Pressure Internal (Note Appendix Table X1, Nos. 9–13)

Type of Specification	Seller	User	Maximum Leakage, $Pa \cdot m^3/s$
Operational		X	1.3×10^{-9}
Testing, total	X		4×10^{-10}
Testing, total		X	1×10^{-10}
Testing, each leak	X		3×10^{-10}
Testing, each leak			1×10^{-10}

Note that the factors used are larger than normal, as the sensitivity limit for the detection of halogen has been approached. (See Practice E 427).

6.6.4.2 *Control Valve*—There are two separate leakages to consider for this component: the refrigerant side and the operational side. Applying appropriate factors, the specifications may be tabulated as follows:

Refrigerant Circuit Side Specifications:

Maximum Leakage at 2.76 MPa Differential, Pressure Internal (Note Appendix Table X1, Nos. 14–17)

Type of Specification	Seller	User	Maximum Leakage, $Pa \cdot m^3/s$
Testing, total			2×10^{-6}
Testing, total	X		2×10^{-7}
Testing, each leak		X	6×10^{-7}
Testing, each leak	X		6×10^{-8}

Calculation, testing, total: $1.8 \times 10^{-4} \times 0.09$ (see the tabulation example in 6.3.2.1) = 1.6×10^{-6} $Pa \cdot m^3/s$.

Operator Specifications:

Maximum Leakage at 0.10 MPa Differential, Pressure External (Note Appendix Table X1, Nos. 18–20)

Type of Specification	Seller	User	Maximum Leakage, $Pa \cdot m^3/s$
Testing, total		X	1×10^{-8}
Testing, total	X		1×10^{-9}

As this component is non-repairable, and because the diaphragm is accessible only through parts on each side of its enclosure, probe testing to locate points of leakage is neither possible nor desirable.

6.6.4.3 *Thermostat*—No parts are in contact with the refrigerant circuit. The unit components usually are sealed in an inert atmosphere at one atmosphere pressure, to prevent contaminants and oxidation. It is preferred to specify the tracer gas to be used, in order to control the electrical characteristics and contact life. As a rule, probing tests are difficult and not necessary, as defective units will be scraped. Test data have revealed that a seal that leaks no more than 1×10^{-7} Pa·m³/s at 0.10 MPa differential will give adequate protection at the normally small operating differentials.

Maximum Leakage at 0.10 MPa Differential, Pressure Internal (Note Appendix Table X1, Nos. 21–23)

Type of Specification	Seller	User	Maximum Leakage, $Pa \cdot m^3/s$
Operational			1×10^{-7}
Testing, total		X	3×10^{-9} [A]
Testing, total	X		3×10^{-10} [A]

[A] Fill to be 10 % helium in dry nitrogen. This value pertains o helium leakage only.

7. Summary of Requirements

7.1 A leakage specification should contain all the requirements for the qualifying procedure. It shall specify:

7.1.1 Mass flow, preferably in $Pa \cdot m^3/s$,

7.1.2 Time, preferably in seconds,

7.1.3 Pressure differential, preferably in Pa,

7.1.4 Direction of pressure differential,

7.1.5 Other restrictions only when necessary, and

7.1.6 Intended use of specifications:

7.1.6.1 Operational.

7.1.6.2 Testing, total.

7.1.6.3 Testing, each leak (optional).

7.1.6.4 Testing, total, seller (optional).

7.1.6.5 Testing, each leak, seller (optional).

APPENDIX

(Nonmandatory Information)

X1. PRELIMINARY LEAK TESTS

X1.1 It should be noted that furnished specifications in no way prevent the manufacturer or seller from making his own interim leak tests. It should be determined, however, that such tests do not prejudice the required tests. For example, a preliminary bubble test under water might temporarily plug small leaks. As an example, consider line 11, Table A1, "Expansion valve operator assembly, seller, max leakage 1×10^{-9} standard cm³/s at 70 psi (0.48 MPa) differential, pressure internal." The seller wishes to test the assembly before fitting and sealing. He elects to use the helium mass spectrometer with 100 % helium external test gas. He computes the expected difference in leak rate:

Factor of Safety

$$= (P_2^2 - P^2)/(P_4^2 - P_3^2)$$
$$= (0.1^2 - 0^2)/(0.57^2 - 0.1^2) = 0.03$$

Therefore he will get a value of $1 \times 10^{-10} \times 0.03 = 3 \times 10^{-12}$ Pa·m³/s. However, in leaks of this size, helium leaks about 7 times faster than R-12. Therefore, he may desire to use the specification value of $3 \times 10^{-12} \times 7 = 2 \times 10^{-11}$ Pa·m³/s as a preliminary test.

TABLE X1 Leakage Specification Developed in Example, Automotive Air Conditioner

No.	Component	Type of Specification	Seller	User	Pressure Internal	Pressure External	Differential, MPa (psi)	Max. Leakage, Pa·m³/s	Methods Considered[A]
1.	Hoses	operational			X		2.07 (300)	1.8×10^{-5}	A1
2.	Refrigerant system except hoses	operational			X		2.07 (300)	1.8×10^{-5}	A1
3.	Refrigerant system except hoses	testing total		X	X		2.76 (400)	6×10^{-6}	A, B
4.	Refrigerant system except hoses	testing, each leak		X	X		2.76 (400)	2×10^{-6}	A, B
5.	Expansion valve refrigeration system	testing total		X	X		2.76 (400)	9×10^{-7}	A, B
6.	Expansion valve refrigeration system	testing total	X		X		2.76 (400)	9×10^{-8}	A, B
7.	Expansion valve refrigeration system	testing, each leak		X	X		2.76 (400)	3×10^{-7}	A2
8.	Expansion valve refrigeration system	testing, each leak	X		X		2.76 (400)	3×10^{-9}	A2
9.	Expansion valve operator assembly	operational			X		0.48 (70)	1.3×10^{-9}	A1
10.	Expansion valve operator assembly	testing total		X	X		0.48 (70)	4×10^{-10}	A1
11.	Expansion valve operator assembly	testing total	X		X		0.48 (70)	1×10^{-10}	A1
12.	Expansion valve operator assembly	testing, each leak		X	X		0.48 (70)	3×10^{-10}	A1
13.	Expansion valve operator assembly	testing, each leak	X		X		0.48 (70)	1×10^{-10}	A1
14.	Control valve refrigeration system	testing total		X	X		2.76 (400)	2×10^{-6}	A, B
15.	Control valve refrigeration system	testing total	X		X		2.76 (400)	2×10^{-7}	A, B
16.	Control valve refrigeration system	testing, each leak		X	X		2.76 (400)	6×10^{-7}	A2
17.	Control valve refrigeration system	testing, each leak	X		X		2.76 (400)	6×10^{-8}	A2
18.	Control valve operator system	operational				X	0.10 (15)	1×10^{3}	A
19.	Control valve operator system	testing total		X		X	0.10 (15)	1×10^{-1}	C3
20.	Control valve operator system	testing total	X			X	0.10 (15)	1×10^{-2}	C3
21.	Thermostat	operational			X		0.10 (15)	1×10^{-7}	B1
22.	Thermostat	testing total		X	X		0.10 (15)	3×10^{-9}[B]	B1
23.	Thermostat	testing total	X		X		0.10 (15)	3×10^{-10}[B]	B1

[A] The last column, "Methods Considered," is not a proper part of the specifications. It and the footnotes were appended to show test methods that were considered.

Methods Considered	Reasons for Suitability
A. Halogen, alkali-diode	1. Inherent tracer
B. Helium mass spectrometer, tracer internal	2. Adequate sensitivity
C. Sensitive flowmeter	3. Quantitative measurement of large leaks

[B] Fill to be 10% helium in dry nitrogen. This value is for helium leakage only.

AVS 2.1 Rev.—1973

Calibration of Leak Detectors of the Mass Spectrometer Type

Air-Vacuum Science and Technology

(Received 11 April 1973)

FOREWORD

This foreword is not part of AVS 2.1. This publication specifies practices tentatively approved as standard by the American Vacuum Society for the calibration of leak detectors of the mass spectrometer type and is one of a series published by the American Vacuum Society. It contains data secured from many sources and represents the best thinking of a number of experts in the field. It is the first issuance of a standard for this topic. After several years of use, this standard will be forwarded to the American National Standards Institute with the request that it be used as a basis for an ANSI Standard. Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the American Vacuum Society, 335 East 45th Street, New York, N. Y. 10017.

The AVS Committees which drafted and approved this Standard had the following personnel at the time of approval:

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CONTENTS

1. SCOPE

This Standard prescribes procedures to be used for calibrating leak detectors of the mass spectrometer type; that is, for determining a sensitivity figure for such leak detectors. The procedures require the use of a calibrated leak and a standard gas mixture; the preparation and standardization of these is outside the scope of this proposal. Hereafter, the designation "leak detector" will be used to refer to a detector of the mass spectrometer type.

A leak detector permits detection of leakage due to mechanical openings, such as pinholes, and of leakage due to permeation, such as occurs through many polymeric materials. Virtual leaks, such as those due to surface desorption, vaporization, and gas pockets cannot, in general, be detected by a leak detector.

Various gases may be used in conjunction with leak detectors. The present document concerns the use of helium −4. Nevertheless, the procedures described may be used for other search gases such as Argon −4,0 subject to appropriate precautions.

The present standard deals only with leak detectors which have an integral high vacuum system to maintain the sensing element (mass spectrometer tube) at a low pressure. Specifically excepted from treatment are sensing elements without such a vacuum system. It is also to be understood that the procedures are not intended to constitute a complete acceptance test; such tests will be the subject of a further document.

The application of this proposal is restricted to leak detectors not capable of detecting leaks smaller than 10^{-11} Torr liters/sec (10^{-12} Pa m^3/sec). Factors that are unimportant for larger leaks may become significant for leak rates that are substantially smaller than 10^{-11} Torr liters/sec (10^{-12} Pa m^3/sec).

Objects being tested by a leak detector may be under high vacuum, or, at the other extreme, under pressure greater than atmospheric. The leak detection techniques will, in general, differ in the two situations. In the first case, the leak detector usually will be operating near its ultimate low pressure; in the second case, the detector is frequently used at or near its maximum operating pressure. Corresponding to these two conditions of operation, two sensitivity terms are defined, minimum detectable leak rate and minimum detectable concentration ratio (see Sec. 3, Definitions). The two quantities thus defined are related, but in practice it is not feasible to obtain either figure from the other by calculation. Methods are therefore specified for determining both.

2. DESCRIPTION OF LEAK DETECTOR

The helium leak detector considered here is essentially a gas analyzer employing the mass-spectrometer principle. In the mass-spectrometer tube, a mixture of gases from the object under test is first ionized, then separated into a series of ion beams or groups, each beam or group ideally representing a single species of gas. (Actually, the ions in each beam have the same mass-to-charge ratio.) In the helium leak detector, means are provided for "tuning" the instrument so that only the beam due to helium hits an ion collector. (The detector can be retuned, generally, to respond to other gases.) The current produced by the beam is amplified, and its magnitude is a measure of the partial pressure of the helium gas in the incoming sample. It will be assumed that the gas ionization is produced by electrons from a hot filament.

Leak detectors consist of a mass-spectrometer tube, a high-vacuum system for maintaining the tube under vacuum with a flow of gas sample through or into the tube, voltage supplies, and an ion-current amplifier. The output of the amplifier can be displayed in a number of ways, and almost invariably an indicating electrical meter is one of the means chosen. For the purposes of the present procedures, however, it will be assumed that the output is shown on a chart recorder. Means are provided for reducing the output so that a large range of leak sizes can be detected and measured. In other words, the leak detector can be set at one of a number of different detection levels, hereafter referred to as sensitivity settings.

Since the spectrometer tube is required to receive a gas sample from the system under test and also to be kept under vacuum, an inlet line is provided for leading gas from the outside into the spectrometer tube, and this line must have an isolation valve ("inlet valve") in it (see Fig. 1.0). Likewise, a pressure-indicating device is also included; the pressure in the spectrometer tube may thus be observed and prevented from exceeding the maximum specified operating pressure.

3. DEFINITIONS

Note: Where a word may be either a noun or a verb, the letters "n" or "v", in parentheses, indicate which usage is involved.

3.1 Background (or Residual Signal)

3.1.1 General

In general, background is the total spurious indication given by the leak detector without injected search gas. Background can originate in either the mass spectrometer tube (see below) or the associated electric and electronic circuitry, or both. (Frequently, the term is used to refer specifically to the indication due to ions other than those produced from injected search gas.)

3.1.2 Drift

The relatively slow change in the background. The significant parameter is the maximum drift measured in a specified period of time.

3.1.3 Noise

The relatively rapid changes in the background. The significant parameter is the noise measured in a specified period of time.

3.1.4 Helium Background

Background due to helium released from the walls of the leak detector or leak detection system.

3.2 Components

3.2.1 Inlet Line (or Sample Inlet Line)

The line through which the search gas passes from the object under test to the leak detector.

3.2.2 Valve, Inlet

A valve which is placed at the end of the sample inlet line and adjacent to the leak detector. See Fig. 1.0. Almost invariably the inlet valve is an integral part of the leak detector.

3.2.3 Valve, Leak Isolation

A valve placed between a leak which is to be used for testing the leak detector and the sample inlet line (see Fig. 1.0).

3.2.4 Valve, Pump

A valve placed between the auxiliary pump used for evacuating the sample inlet line and that line (see Fig. 1.0).

3.2.5 Valve, Vent

A valve used to admit air or other gas into an evacuated space so as to increase the pressure therein to atmospheric pressure.

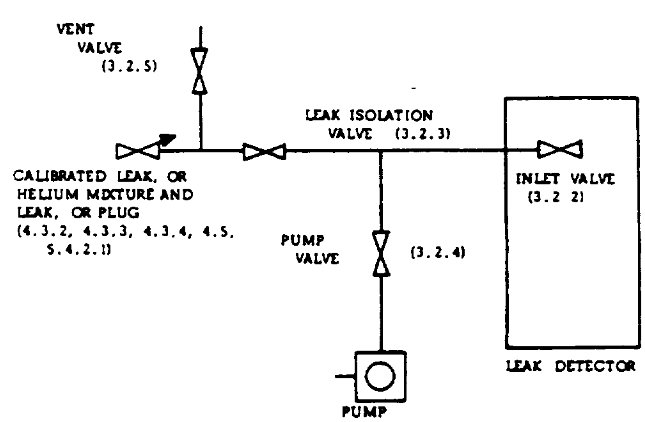

FIGURE 1.0. Test arrangement.

3.2.6 Backing-off Control (or Zero Control)

An electrical control, present on most leak detectors, which may be used to shift the output indication of the device. Frequently, the backing-off control is used to return the output indication to zero of the scale, whence the alternative name.

3.2.7 Filament

The source of the (thermal) electrons which ionize the gases in the mass-spectrometer tube; the filament is located in this tube.

3.2.8 Mass-Spectrometer Tube

That element of a leak detector in which the search gas is ionized and detected.

3.3 Search Gas

A gas applied to the outer surface of equipment under leak test and detected, after entry into the equipment through the leak, in a vacuum test; or introduced into the equipment under test and detected after it is emitted from the leak in a pressure test.

3.4 Leaks

3.4.1 Leak (n)

In vacuum technology a hole, porosity, permeable element, or other structure in the wall of an enclosure capable of passing gas from one side of the wall to the other under action of a pressure or concentration difference existing across the wall.

Also, a device which can be used to introduce gas into an evacuated system.

3.4.1.1 Channel leak. A leak which consists of one or more discrete passages that may be ideally treated as long capillaries.

3.4.1.2 Membrane leak. A leak which permits gas flow by permeation of the gas through a nonporous wall. For helium, this wall may be of glass, quartz, or other suitable material.

3.4.1.3 Molecular leak. A leak through which the mass rate of flow is substantially proportional to the reciprocal of the square root of the molecular weight of the flowing gas.

3.4.1.4 Viscous leak. A leak through which the mass rate of flow is substantially proportional to the reciprocal of the viscosity of the flowing gas.

3.4.2 Calibrated Leak

A leak device which provides a known mass rate of flow for a specific gas under specific conditions.

3.4.3 Standard Leak

A calibrated leak for which the rate of leakage is known under standard conditions, namely, 23 ± 3°C, a pressure of 760 Torr $\pm5\%$ at one end of the leak, and a pressure at the other end so low as to have a negligible effect on the leak rate.

3.4.4 Virtual Leak

The semblance of a leak due to evolution of gas or vapor within a system.

3.5 Leak Rates

3.5.1 Leak Rate

The mass rate (also called "throughput"; differentiated from volume rate of flow (liters/sec) also called "pumping speed"), in Torr liters/sec (or Pa m^3/sec) at which a specific gas passes through a leak under specific conditions.

3.5.2 Standard Air Leak Rate

The mass rate of flow, through a leak, of atmospheric air of dew point less than -25°C under standard conditions specified as follows: the inlet pressure shall be 760 Torr $\pm5\%$, the outlet pressure shall be less than 10 Torr and the temperature shall be 23 ± 3°C.

3.5.3 Equivalent Standard Air Leak Rate

Short-path leaks having standard air leak rates less than 10^{-6}–10^{-7} Torr liters/sec (10^{-7}–10^{-8} Pa m^3/sec) are of the molecular type (see Sec 3.4.1.3). Consequently, helium (mol. wt 4) passes through such leaks more rapidly than air (mol. wt 29) and a given flow rate of helium corresponds to a smaller flow rate of air. In this recommendation, helium flow is measured and the "equivalent standard air leak rate" is taken as $(4/29)^{\frac{1}{2}}=0.37$ times the helium leak rate under standard conditions (see Sec 3.5.2).

3.6 Operation of the Leak Detector

3.6.1 Peak (n)

The trace showing a maximum on the chart recorder when a leak detector is scanned (see below) with gas present, usually the search gas, to which the detector is sensitive.

3.6.2 Peak (v)

To so set the scanning control (see Scan below) of a leak detector that the output due to a given search gas input is maximized. This is a form of tuning.

3.6.3 Scan (v)

To vary the accelerating voltage (or other equivalent operating parameter) of a leak detector, particularly across that range of voltage which includes the voltage necessary to produce a search gas peak.

3.6.4 Tune (v)

In leak-detection technology, to adjust one or more of the controls of a leak detector so that its response to a search gas is maximized. Tuning by means of the scanning control only is called "peaking."

3.6.5 Zero (v)

To adjust the zero or backing-off control so that the output indication of the leak detector is at the zero of the indicating scale or at some other reference point.

3.7 Relative Gas Concentration

3.7.1 Concentration Ratio

Same as Mole Fraction (below).

3.7.2 Mole Fraction

The ratio of the number of atoms (or molecules) of a given constituent of a mixture to the total number of atoms (or molecules) in the mixture. For ideal gases, the mole fraction has the same value as the fraction based on volume; in general, leak detectors are operated in the pressure range where gases behave ideally. (This is the same as concentration ratio.)

3.7.3 Partial Pressure

In a mixture of gases, the partial pressure of a constituent is the product of the total pressure of the mixture and the mole fraction or concentration ratio of the given constituent.

3.8 Sensitivity Terms

3.8.1 Sensitivity

The sensitivity of a device is the change in output of the device divided by the change in input which caused the response.

3.8.2 Minimum Detectable Signal

An output signal due to incoming search gas which is equal in magnitude to the sum of the noise and the drift.

3.8.3 Minimum Detectable Leak (or Minimum Detectable Leak Rate)

The smallest leak, as specified by its standard air leak rate, that can be detected unambiguously by a given leak detector (see Sec. 1). The minimum detectable leak rate depends on a number of factors. One of the purposes of this Standard is to describe practical procedures for determining minimum detectable leak rate, taking into account background, volume rate of flow (pumping speed), and time factor.

3.8.4 Minimum Detectable Concentration Ratio

The smallest concentration ratio of a given search gas in an air mixture that can be detected unambiguously by a given leak detector when the mixture is fed to the detector at such a rate as to raise the pressure in the instrument to some optimum high value. In this Standard, the minimum detectable leak rate is calculated—by a somewhat arbitrary procedure—from observations of the response of the leak detector to a helium–air mixture of known helium concentration ratio (see Sec. 1).

3.9 Time Factors

3.9.1 Time Constant

The time interval required for the output of an instrument or system to change by $1-1/e$ or 63% of the ultimate (steady-state) output change produced by an abrupt change in input.

3.9.2 Response Time T

The time constant corresponding to a change from a zero or small leak-rate indication, to a positive or large leak-rate indication.

3.9.3 Cleanup Time (or Clearing Time)

The time constant corresponding to a change from a positive leak rate indication, of limited magnitude, to a small or zero leak-rate indication.

N.b. In this standard, response time and cleanup time are assumed to be equal.

4. TEST CONDITIONS AND APPARATUS

4.1 Ambient Temperature

Ambient temperature should be 23 ± 3°C.

4.2 Ambient Pressure

Ambient pressure should be 760 Torr ±5%. When deviation from 760 Torr exceeds 5%, appropriate correction shall be made, with 5% tolerable inaccuracy.

4.3 Leaks

4.3.1 General

Two leaks may be required: one with a relatively small leak rate and the other with a relatively large leak rate. The small leak is used for determining minimum detectable leak, the large leak for minimum detectable concentration ratio. The small leak should be calibrated and may be of the channel type or of the membrane type; preferably, the large leak should be capable of being adjusted to vary its leak rate, but this is not essential. The leaks are specified in the following.

4.3.2 Small Channel Leak

This should have a leak rate such that when helium, at 760 Torr pressure and 23 ± 3°C, is fed to the leak and thence to the leak detector under test, a deflection is produced on the recorder chart which is not less than 50 times the minimum detectable signal (see Sec. 5.3 below). The leak detector should have been adjusted as in 4.6 below. A temperature correction should be specified for the leak and this correction applied for the difference between the temperature of the leak at the time of use and the temperature at which the leak was calibrated.

4.3.3 Small Membrane Leak

This should have its own integral, sealed source of helium at not less than 760 Torr pressure. It should leak the helium at a rate which will produce a deflection as specified under Small Channel Leak, Sec. 4.3.2, above. A temperature correction should be specified for the leak, and this correction applied for the difference between the temperature of the leak at the time of use and the temperature at which the leak was calibrated.

4.3.4 Large (Adjustable) Leak

This should be a viscous leak, either fixed or so adjusted that when connected to the leak detector with ambient air at the inlet side of the leak, the pressure in the leak detector rises to the optimum high operating pressure (±50%) specified by the manufacturer.

4.4 Helium

This should be at least 99.9% helium (available from commercial dealers in bottled gases).

4.5 Helium Mixture

This should be helium and air mixture of a known helium concentration ratio such that it produces a deflection of at least 10 times the minimum detectable signal (see Sec. 6.4) when fed at a pressure of 760 Torr ±5% and at a temperature of 23±3°C to the large (adjustable) leak (4.3.4 above) and thence into the leak detector under test. Where applicable, atmospheric air may be used as the helium mixture. In either case, the air for the mixture should be obtained from a point at least 2 m outside the walls of the building housing the test equipment. Helium concentration ratio shall be represented by the symbol C_M and should be expressed as a fraction with numerator reduced to unity. Alternatively, the concentration ratio may be expressed in parts of helium per million parts of mixture (parts per million by volume). The concentration ratio of helium in air should be taken arbitrarily as 1/200 000 or 5 parts per million, and this figure should be taken into account when preparing mixtures containing more helium. (Note: The latest data indicate 5.24 parts per million of helium in air by volume—E. Glueckauf, ***Compendium of Meteorology***, edited by T. F. Malone (American Meteorological Soc., Boston, 1951), pp. 3–10.)

4.6 Leak Detector

4.6.1

The leak detector should have been connected to a power source conforming in voltage, frequency, and regulation to the manufacturer's specifications.

4.6.2

The leak detector should have been "warmed up", as specified by the manufacturer, prior to all test procedures.

4.6.3

The leak detector under test should have been adjusted for optimum detection of helium in the manner specified by the manufacturer.

4.6.4

If the vacuum system of the leak detector is such as to permit adjustment of volume rate of flow (pumping speed), the selected rate should not be varied during the test.

4.7 Chart Recorder

4.7.1

This should be an instrument of at least 1-h recording time suitable for recording the output of the leak detector under test.

The time constant of the recorder should be small enough to introduce no error in the response time of the leak detector.

There should be negligible interaction between the recorder and the output indicating meter, i.e., the velocity of the pointer of either should not generate sufficient electrical signal to affect the indication of the other. If the recorder is connected in parallel with the meter, this interaction will be negligible if each has an input resistance 200 times that of their common voltage source.

4.7.2

The recorder should be adjusted so that full scale on the recorder corresponds to full scale of the leak detector output meter when the leak detector is at its most sensitive detection setting and so that zero of the recorder corresponds to zero of the output meter.

4.8 Apparatus

This is illustrated diagrammatically in Fig. 1.0.

5. TEST PROCEDURE—MINIMUM DETECTABLE LEAK

5.1 Drift and Noise Observation

5.1.1

The output of the leak detector is connected to the recorder, the leak detector being at its maximum sensitivity setting and the inlet valve closed. See also Sec. 4.6.

5.1.2

The leak detector backing-off (or zero) control is adjusted so that the recorder reading is approximately 50% of full scale, the filament being on.

5.1.3

The output is recorded for 20 min or until the output has reached full scale, for positive drift, or zero, for negative drift.

5.1.4

Draw a series of line segments intersecting the curve recorded in Sec. 5.1.3, the lines to be drawn at 1-min

intervals at right angles to the time axis (abscissa) of the chart, and to commence at the point where the procedure of Sec. 5.1.3 is started. The lines so drawn will be called the "1-min lines".
Draw straight-line approximations for each segment of the curve between adjacent 1-min lines.

5.2 Drift and Noise Determination

5.2.1

Examine the straight line approximations of Sec. 5.1.4 to determine that 1-min segment of the output curve having the greatest slope. This greatest slope is measured in scale divisions per minute and is called the *drift*. If the greatest slope is less than the scale divisions corresponding to 2% of full scale of the recorder, the total (absolute) change in output over the 20-min period is determined. The total change divided by 20 is then called the drift.

5.2.2

For each 1-min segment of the curve, determine the maximum (absolute) deviation of the recorded curve from the straight-line approximation.

5.2.3

The average of these maximum deviaitons, multiplied by 2, is called the noise (scale divisions).

Note: In determining the noise, neglect any large deviation (spike) which occurs less frequently than once in any 5-min interval.

5.3 Minimum Detectable Signal

The minimum detectable signal is taken to be equal to the sum of the absolute values of the drift and of the noise. It should be measured in scale divisions. If the sum is less than the scale divisions corresponding to 2% of full scale, then the scale divisions corresponding to 2% of full scale is called the minimum detectable signal.

5.4 Sensitivity Determination

5.4.1 Arrangement of Apparatus

The leak detector is connected to an auxiliary system as shown in Fig. 1.0. (Frequently, the auxiliary system is included with the leak detector as an integral part thereof.)

The system should contain a minimum of rubber or other polymeric surfaces. Preferably, such surfaces should consist only of the exposed surfaces of an O-ring or O-rings. Accordingly, the "Leak Isolation Valve" shown in Fig. 1.0 should preferably be of all-metal construction, but in any case should not act as a significant source of adsorbed or absorbed helium.

5.4.2 Spurious Signal Correction

Note: This determination requires the use of the small calibrated leak. If the calibrated leak has its own integral valve, and the leak and valve are of all-metal construction (except perhaps for the membrane in a membrane-type leak), Sec. 5.4.2 may be omitted from the procedure.

5.4.2.1. A metal plug is connected to the leak detector as indicated on the left side of Fig. 1.0.

5.4.2.2. The output is zeroed, with the filament on.

5.4.2.3. The leak isolation valve is opened.

5.4.2.4. The pump valve is opened.

(Note: For its safety, the filament of the mass spectrometer tube may be turned off at this point.)

5.4.2.5. When the atmospheric air present between the plug and the inlet valve has been evacuated, the pump valve is closed.

5.4.2.6. The inlet valve is opened promptly, but gradually. The pressure in the leak detector is allowed to reach a steady value, showing no observable change in a 1-min period.

5.4.2.7. Turn on filament of mass spectrometer tube if it is not on.

5.4.2.8. When the output has reached a steady value, but in any case not longer than 3 min after Sec. 5.4.2.6, the output reading is noted. If the leak detector has been set at reduced sensitivity, the reading should be converted to equivalent scale divisions for full-sensitivity setting.

5.4.2.9. Close the leak isolation valve as rapidly as feasible.

5.4.2.10. Note the output reading 10 sec after closing the isolation valve. As in 5.4.2.8, convert the reading if necessary.

5.4.2.11. Subtract the reading noted in 5.4.2.10 from that noted in 5.4.2.8. If the difference is negative, it is to be considered equal to zero. The difference will be called the "spurious-signal correction" and will be applied in Sec. 5.4.3.14.

5.4.2.12. Close the inlet valve.

5.4.2.13. Open the vent valve.

5.4.2.14. Remove only the plug from the inlet line; all connections are to remain in place.

5.4.2.15. Close the vent valve.

5.4.3 Sensitivity

5.4.3.1. Connect the all-metal leak to the leak detector. However, if the procedure of 5.4.2 was necessary, the small calibrated leak is put in place of the plug removed in 5.4.2.14 above, the leak being inserted the same distance into the connection as the plug had been.

5.4.3.2. The output is zeroed with the filament on.

5.4.3.3. The leak isolation valve is opened.

5.4.3.4. The pump valve is opened.

5.4.3.5. Helium at 760 Torr ±5% pressure is applied to the leak. If the leak has its own supply of helium, this step is omitted.

(Note: The filament of the mass spectrometer tube may be turned off before Sec. 5.4.3.6.)

5.4.3.6. When the atmospheric air present between the calibrated leak and the leak detector has been evacuated, the pump valve is closed.

5.4.3.7. The inlet valve is opened .promptly after

Sec. 5.4.3.6. The pressure in the leak detector is allowed to reach a steady value, showing no observable change in 1 min.

5.4.3.8. Turn on filament of mass spectrometer tube if it is not on.

5.4.3.9. At this point it may be necessary to change the sensitivity setting. When the output signal has reached a steady value, showing a change in 1 min which is not greater than the drift (as corrected for the sensitivity setting), the output reading in scale divisions is noted. If the leak detector has been set at reduced sensitivity, the reading should be converted to the equivalent scale divisions for full-sensitivity setting.

5.4.3.10. Immediately after the preceding step, the stopwatch is started and simultaneously the leak isolation valve is closed *as rapidly as practical*. Alternatively, the recorder chart may be marked to indicate the beginning of the timed period and the leak isolation valve then closed rapidly.

5.4.3.11. The output is observed continuously and the stopwatch is stopped when the reading has decreased to 37% of the reading observed in Sec. 5.4.3.9 above. The reading of the stopwatch is noted (T sec). Alternatively, the recorder chart is examined to determine the time T required for the specified decrease in output. T is the response time (Sec. 3.9.2).

Note: Should response time be a function of sensitivity setting, T as observed should be corrected to response time at full sensitivity setting, if any other setting was used.

5.4.3.12. One minute after closing the leak valve (see Sec. 5.4.3.10), the output is read and noted. Correct for sensitivity setting as in 5.4.3.9.

5.4.3.13. The uncorrected signal due to the calibrated leak shall be taken as the difference between the reading noted in 5.4.3.9, and that noted in 5.4.3.12, the required conversion of these readings to equivalent scale divisions at full-sensitivity setting having been made.

5.4.3.14. The corrected signal due to the calibrated leak is taken as the difference between the uncorrected signal, Sec. 5.4.3.13, and the spurious signal correction in 5.4.2.11. The sensitivity is calculated by the formula below and should always be stated together with the response time, T:

$$\text{Sensitivity, with Response Time } T = \frac{\text{Signal due to Calibrated Leak}}{\text{Standard or Equivalent Standard Air Leak Rate of Calibrated Leak}}$$

The units are scale divisions (on full sensitivity setting) per unit leak rate (Secs. 3.5 and 3.8).

5.5 Minimum Detectable Leak

Referring to Secs. 5.3 and 5.4.3.14, this is calculated from the formula

$$\text{Minimum Detectable Leak, with Response Time } T = \frac{\text{Minimum Detectable Signal}}{\text{Sensitivity}}$$

The units are those of leak rate.

6. TEST PROCEDURE—MINIMUM DETECTABLE CONCENTRATION RATIO

6.1 General

The determination of minimum detectable concentration ratio requires means within the leak detector under test for scanning the helium peak. This means is generally an adjustment of the accelerating voltage, and it will be assumed that this is the case (see Sec. 3.6.3). When leak-detector output (scale divisions) is plotted against accelerating voltage, a curve is obtained, whose general features are illustrated by the solid line in Fig. 2.0. The rise in the curve to a peak at B is due to the presence of helium. The faired curve indicated by a broken line is due to a varying background signal contributed by other ions in the absence of helium. With helium present, and in the absence of background, the curve obtained would be symmetrical, falling off asymptotically to zero on either side of the peak voltage. The curve shown in Fig. 2.0 is very nearly a direct superposition of the background curve and the symmetrical pure-helium curve.

It should be noted that as the voltage is varied from the left side of the graph to the right, the output first decreases, then increases, and finally decreases again. This reversal in direction, indicating the presence of helium, is very easily detected when the scan is being observed visually on a meter. As the helium input is progressively reduced in absence of helium background, the reversal becomes smaller until eventually a curve, such as is shown by the solid line in Fig. 2.1, is obtained. Under these conditions the output never reverses; it remains constant for a very short voltage interval. Such a condition will barely be detected by the usual visual observations. In the absence of noise and drift, the concentration ratio of helium which produces this condition determines the Minimum Detectable Concentration Ratio.

Helium background gives rise to a trace similar to that of Figure 2.0. The total situation is illustrated by

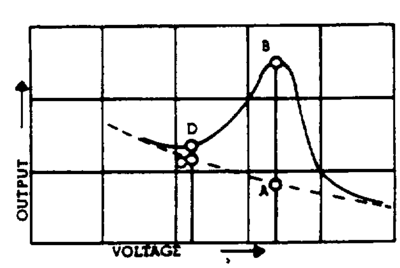

FIGURE 2.0. Typical helium scan.

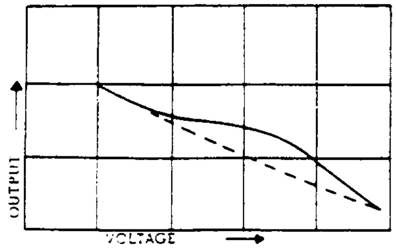

FIGURE 2.1. Scan in absence of helium.

Fig. 2.2. The first (lowest) solid-line curve represents the minimum detectable concentration ratio. The next curve represents the helium output due to background in the absence of injected helium. The third curve represents the output due to incoming helium plus helium background.

In the following determination the helium background is called the spurious signal.

Under practical conditions it is not possible to make a rigidly correct determination of the minimum detectable concentration ratio as defined above. In the following, somewhat arbitrary determinations are used for calculating a sensitivity figure. The minimum detectable concentration ratio so obtained is one that is reasonable in light of practical experience.

6.2 Drift and Noise Observation

6.2.1

The output of the leak detector is connected to the recorder, the leak detector being at its maximum sensitivity setting, the inlet valve closed, and the filament off. See Sec. 4.6.

6.2.2

The leak detector is connected to an auxiliary system as shown in Fig. 1.0 and further specified in Sec. 5.4.1.

6.2.3

The large leak (calibrated or adjustable) is connected to the leak detector. See Fig. 1.0.

6.2.4

Atmospheric air or a helium mixture (see Sec. 4.5) is fed, at 760 Torr ±5%, to the leak. In case atmospheric air is used, the feed line should not of itself act as a source of helium and preferably should be of all-metal construction.

6.2.5

The leak isolation valve is opened.

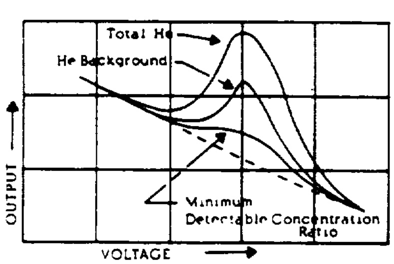

FIGURE 2.2. Total effects scan.

6.2.6

The pump valve is opened.

6.2.7

When the atmospheric air present between the leak and the inlet valve has been evacuated, open the inlet valve.

6.2.8

Close the pump valve.

6.2.9

If an adjustable leak is being used, adjust it to bring the pressure in the leak detector to its optimum value as specified in Sec. 4.3.4.

6.2.10

Turn on the filament and adjust the sensitivity control, if necessary, to the highest sensitivity setting that will result in an on-scale recorder indication.

6.2.11

Adjust the zero control (backing-off control) so that the recorder reading is as near to 50% of full scale as possible.

6.2.12

The output is recorded for 20 min or until the output has reached full scale, for positive drift, or zero for negative drift. This record is called the ***drift curve***.

6.2.13

Set the sensitivity control on full-sensitivity setting. If the indication is off-scale bring it to midscale by means of the zero (backing-off) control. If this is not possible, set the sensitivity control to the highest sensitivity setting that will produce an on-scale indication; then bring the indication to midscale by means of the backing-oft (zero) control.

6.2.14

The output is recorded for 20 min or until the output is off-scale. This record is called the ***noise curve***.

6.2.15

Treat the drift and noise curves as in Sec. 5.1.4.

6.3 Drift and Noise Determination

6.3.1

Determine the drift from the drift curve as in 5.2.1, correcting for any reduced sensitivity setting.

6.3.2

Determine the noise from the noise curve as in Secs. 5.2.2 and 5.2.3.

.4 Minimum Detectable Signal

.4.1

This should be calculated as in Sec. 5.3.

:5 Spurious Signal Determination

.5.1

With the equipment as it was at the end of Sec. 6.2.13, lose the leak isolation valve and turn on the filament f it is not already on.

6.5.1.1. Set the leak detector for the greatest sensi- ivity that will give on-scale readings. (If necessary, eadjust scanning control for helium peak.)

6.5.1.2. When the output signal has reached a steady alue, showing no observable change in 1 min, scan the elium peak as specified for the instrument. The output vill, in general, produce a curve of the form shown in ig. 2.0. The curve is faired, as is also shown in the igure by the dashed line.

The ordinate AB is to be taken as a measure of the elium background, B being located at the maximum f the curve and A directly below B.

6.5.1.3. If AB is not zero, the scanning is to be re- eated at 15-min intervals until AB has become zero r has not changed over a ½-h period.

6.5.1.4. If AB is ultimately different from zero, its nagnitude is determined and is referred to as the purious signal (s.s.) (scale divisions). If the leak de- ector is at reduced sensitivity setting, the s.s. should e converted to equivalent scale divisions at full-sensi- ivity setting.

.6 Minimum Detectable Concentration Ratio

.6.1

Close the inlet valve.

.6.2

Open the leak isolation valve.

.6.3

Open the pump valve.

(Note: The filament may be turned off at this point.)

.6.4

When the air present between the leak and the inlet alve has been evacuated, open the inlet valve.

6.6.5

Close the pump valve.

6.6.6

When the pressure in the leak detector has reached a steady value, showing no change in 1 min, turn on the filament if it is not on.

6.6.7

When the output signal has reached a steady value, showing no change in 1 min which is greater than the drift (Sec. 6.3.1), scan the helium peak as specified for the instrument. The output will, in general, produce a curve of the form shown in Fig. 2.0. The curve is faired, as is also shown in Fig. 2.0 by the dashed line.

6.6.8

Mark on the curves the point B (scan maximum), point A (directly below B), point D (scan minimum), and point C (directly below D). Measure the distances of points B, A, and C from the abscissa (voltage axis) of the chart (scale divisions) and denote these ordinates, respectively, by b, a, and c. If the leak detector is at reduced sensitivity setting, the ordinate should be converted into equivalent scale divisions at full-sensitivity setting.

6.6.9 Minimum Detectable Concentration Ratio

The minimum detectable concentration ratio should be calculated by the following formula:

$$\text{Minimum Detectable Concentration Ratio} = \frac{C_M(c-a)}{b-a-\text{s.s.}}.$$

where C_M is the concentration ratio of helium mixture (see Sec. 4.5) and s.s is the spurious signal (see 6.5.1.4). Or, if $c-a$ is less than the minimum detectable signal (M.D.S., see Sec. 6.4), use the formula

$$\text{Minimum Detectable Concentration Ratio} = \frac{C_M(\text{M.D.S.})}{b-a-\text{s.s.}}.$$

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Method for Vacuum Leak Calibration

Am. Vacuum Science and Technology
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FOREWORD

This foreword is not a part of AVS 2.2–1968. This publication specifies practices tentatively approved as standard by the American Vacuum Society for the calibration of leaks in the range 10^{-5} to 10^{-3} atm cm³/sec and is one of a series published by the American Vacuum Society. It contains data secured from many sources and represents the best thinking of a number of experts in the field. After several years of use this standard will be forwarded to the USA Standards Institute with the request that it be used as a basis for a USA Standard. Suggestions for improvement gained in the use of this Standard will be welcome. They should be sent to the American Vacuum Society, 335 East 45th Street, New York, New York 10017. This Standard was drafted by Mr. Albert Nerken. The AVS Standards Committee, which approved this Standard, had the following personnel at the time of approval:

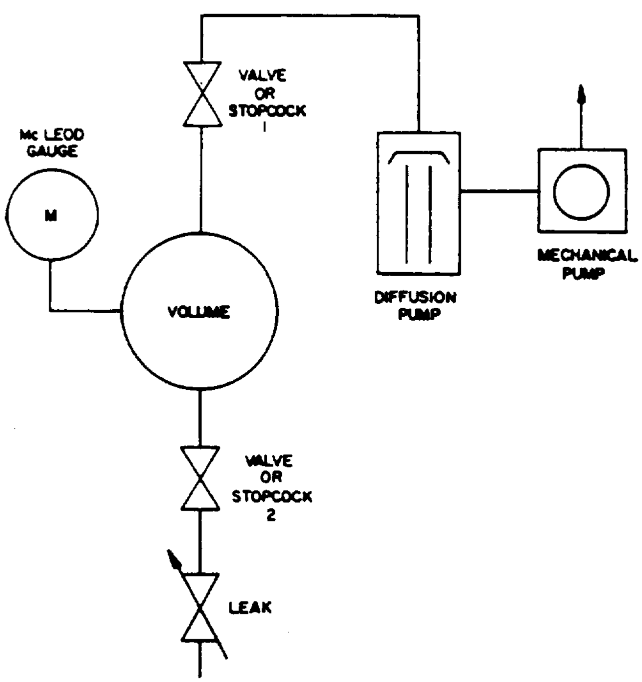

FIGURE 1. Diagram of vacuum system.

AVS Standards Committee

D. G. Bills, Chairman, *Granville-Phillips Company*
B. B. Dayton, *Consolidated Vacuum Corp.*
A. Guthrie, *California State College–Hayward*
D. P. Johnson, *National Bureau of Standards*
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G. Osterstrom, *Welch Scientific Co.*
F. Reinath, *University of California*
S. Ruthberg, *National Bureau of Standards*
H. Schwarz, *Rensselaer Polytechnic Institute*
D. Stevenson, *Consolidated Vacuum Corp.*
P. Varadi, *Machlett Laboratories, Inc.*
W. Wheeler, *Varian Associates*

1. SCOPE

This standard describes an apparatus for measuring the leak rate of vacuum leaks, in the range of 10^{-5} to 10^{-3} atm cm³/sec, and a procedure for using the apparatus to determine such leak rates. The procedure involves a determination of the time rate of change of the pV product, produced in a fixed volume, by the gas entering through the leak under examination. Because a McLeod gauge is used for measuring the pressure and because the only other quantities that require determination are volume and time, the method is an absolute one.

2. APPARATUS

2.1. Vacuum System. The required vacuum system is shown schematically in Fig. 1. The component parts are described below. The material of construction may be glass and/or metal; construction methods should follow approved high-vacuum techniques.

2.1.1. Diffusion Pump. This may be of the oil type and should have a speed greater than 5 liters/sec.

2.1.2. Mechanical Pump. This should be sized to back properly the diffusion pump.

2.1.3. Cold Trap. A cold trap is not essential and is not shown in Fig. 1. However, a trap may be placed between the diffusion pump and the rest of the system.

2.1.4. Valves or Stopcocks. Either metal valves or glass

Approved by American Vacuum Society, Inc., 5 July 1968.

stopcocks may be used in the positions shown. The construction should be such as to present a minimum of outgassing material and surface to the Volume. In the following, the term "valve" is to be understood to mean valve or stopcock, as the case may be.

2.1.5. Volume. This should have a content of not less than 1 liter nor more than 2 liters.[1] Hereafter, the term Volume, capitalized, will be used to refer to this component.

2.1.6. McLeod Gauge. This shall be useful over the range of 0.001 Torr to at least 0.250 Torr. The internal volume of the McLeod above the cutoff point should preferably not exceed one-half of that of the Volume.[2]

2.1.7. Connections. The size of connecting tubing is not critical except for the connection between the Volume and the McLeod gauge. This should be not more than 50 cm long and not less than 0.8 cm in internal diameter.

2.2. Stopwatch. A stopwatch is required in the procedure; it should have $\frac{1}{5}$-sec divisions or smaller.

2.3. Calibration of Apparatus.

2.3.1. McLeod Gauge. The McLeod gauge should be calibrated for pressure in accordance with the pertinent AVS Standard(s).

2.3.2. Total Volume of Apparatus. It will be necessary to know the volume of the apparatus between the two valves, including the volume of the McLeod gauge above the cutoff point and that of the connecting tubing between the Volume and the McLeod gauge. This combined volume will be referred to as the Total Volume. The Total Volume may be determined by filling the apparatus with a suitable liquid and then measuring the volume of the liquid by decanting into a volumetric cylinder or other measuring device. If this is not feasible, the volume of the various parts may be determined individually.

2.3.2.1. Volume. The internal content of the Volume may be determined by the method described above or by filling with a liquid of known density and weighing.

2.3.2.2. McLeod Gauge. If the general procedure of *2.3.2.* is not feasible, the volume of the McLeod gauge may be obtained from its calibration. If this latter is not available, the gauge volume should be estimated by measuring its external dimensions and calculating the volume after allowance for the thickness of the glass. The determination of volume by measuring external dimensions is permissable only when volume of the gauge is not greater than 15% of that of the Volume. If the McLeod gauge volume is larger than this, it will be necessary to find its volume from the original calibration procedure or an equivalent procedure.

2.3.2.3. Connecting Tubing. The volume of the connection between the Volume and the McLeod gauge may be determined by the liquid method or by measurement of dimensions.

3. TEST CONDITIONS

3.1. Ambient temperature shall be 23° ± 3°C.

3.2. Ambient pressure shall be 760 Torr ±5%. If the ambient pressure differs from 760 Torr by more than ±5%, air from a constant pressure source at 760 Torr pressure is to be fed to the leak. A satisfactory source is a volume, of not less than 2-liters capacity, filled with air at 760 Torr pressure at least as often as every 8 h of use.

4. BACKGROUND CORRECTION

4.1. Remove the leak and replace with a degreased metal plug. The connection shall be designed to produce a minimum of outgassing.

4.2. Open valves 1 and 2.

4.3. Evacuate the system by means of the mechanical pump.

4.4. Turn on the diffusion pump.

4.5. After 1 h, measure the pressure in the system by means of the McLeod gauge. Repeat the pressure measurement at 15-min intervals until the same reading is obtained in three successive measurements. Record this reading.

4.6. Close valve 1 and simultaneously start the stopwatch.

4.7. At the end of 15 min, read the McLeod gauge and record the reading.

[1] The calibration procedure involves determination of the product pV. If V is 1 liter (neglecting McLeod gauge volume, see Ref. 2, below) then pV will be 0.25 Torr liter when the McLeod is at the high-pressure end of its range. Since the measurement time is 15 min (Sec. 5.6.), the largest leak that can be measured is $0.25/(15 \times 60)$ or roughly 2.5×10^{-4} Torr liters/sec. If larger leaks are to be measured, a larger Volume may be used and/or a McLeod which is able to measure larger pressures.

[2] Owing to the resistance of the connection between the Volume and the McLeod gauge, there will be a pressure difference between the two components. This pressure difference increases, for a given Volume, with the resistance of the connection and with the internal volume of the gauge. Assume a Volume of 1 liter and a resistance limited as in Sec. *2.1.7.* Then if the McLeod volume is one-half that of the Volume, the maximum error in the leak rate caused by the pressure difference is about 1.5%. However, the 1.5% error applies only to the first 3-min observation; the percentage error decreases directly with time from then on. Averaged over five readings (Sec. 5.6.), the error is approximately 0.5%. If the McLeod volume is equal to that of the Volume, the leak rate error is about 1%. If the Volume is 2 liters, then the error is twice as great for a given McLeod volume ratio.

4.8. If the reading obtained in 4.7 does not differ from that recorded in 4.5 above, the background correction is zero.

If the reading differs from that recorded in 4.5, subtract the latter reading from that obtained in 4.7. Divide the difference by 5. Call the result Δp_0; it is the pressure increment per 3-min interval in the absence of the leak, and constitutes the background correction.

4.9. Close valve 2.

4.10. Remove the plug in valve 2 and replace the leak.

5. PROCEDURE

5.1. If the volume between valve 2 and the leak is not less than 1% of the total volume between the stopcocks, its volume should be determined, either by a displacement method or by measurement of the external dimensions. This volume shall be added to the previously determined Total Volume (*2.3.2* above).

5.2. Open valves 1 and 2.

5.3. Measure the pressure in the system by means of the McLeod gauge. Repeat the pressure measurement at 15-min intervals until the same reading is obtained in two successive measurements. Record this reading.

5.4. Close valve 1 and simultaneously start the stopwatch.

5.5. At the end of 3 min raise the mercury in the McLeod gauge. The level of the mercury in the gauge should be as close as feasible to the cutoff point so that the gauge may be cut off as close to the end of the 3-min period as possible. Read and record the reading.

5.6. Repeat the McLeod gauge reading at 3-min intervals up to a total elapsed time of 15 min, recording each reading.[3]

5.7. Close valve 2 and open valve 1 so that the system may be pumped down for another determination.

6. CALCULATION

6.1. Determine the increase in pressure in each 3-min interval by subtracting the initial pressure reading for the interval from the final pressure reading for the interval.

[3] If the volume of the McLeod gauge is substantially in excess of 150 to 200 ml, the 3-min period between readings may not be sufficient for a careful reading to be taken. In such case, the time interval may be increased, with obvious changes in the determination and calculation of background correction (Sec. 4.) and of leak rate (Sec. 5 and 6.).

6.2. Determine the average of the five pressure increments. Call this average Δp_{av}.

6.3. The leak rate is then determined from the formula:

L. R. $= (\Delta p_{av} - \Delta p_0)V/(3 \times 60)]$ Torr liters/sec at 23°C.

where

L. R. = Leak Rate

Δp_{av} = Average pressure increment, in Torr, as determined in 6.2 above.

Δp_0 = Background correction (4.8).

V = Total Volume of apparatus in liters.

6.4. To convert the above leak rate to atm cm³/sec at 23°C, multiply by 1000/760.

APPENDIX I: ERROR DERIVATION

In Ref. 2 it is pointed out that a difference in pressure will exist between the Volume and the McLeod gauge. This pressure difference results in an error in the leak rate determined by the procedure of this Tentative Standard. Estimates of this error are also given in the Ref. 2. These estimates are based on a theoretical calculation. In the calculation, the content of the Volume is denoted by V_1, the volume of the McLeod gauge by V_2, and these volumes are assumed to have no resistance. The two volumes are connected by a tube of resistance R, and the tube is assumed to have negligible (zero) volume. (In this procedure, R is assumed to be zero.) The gas from the leak enters V_1, part of the gas then flowing to V_2 through R; the flow is assumed molecular in type.

Then, if L denotes the leakage rate of the leak being calibrated, P_1, the pressure at any time in V_1, and P_2, the pressures at any time in V_2,

$$L dt = V_1\, dP_1 + V_2\, dP_2. \tag{1}$$

Let Q be the rate at which gas flows from V_1 into V_2. Then,

$$V_2\, dP_2 = Q\, dt.$$

But, for molecular flow

$$Q = (P_1 - P_2)/R$$

so that

$$V_2\, dP_2 = [(P_1 - P_2)/R]\, dt. \tag{2}$$

Equations (1) and (2) can be solved to give

$$P_2 = \frac{L}{V_1 + V_2} \cdot \left\{ t + \frac{RV_1}{\frac{V_1}{V_2} + 1} \left[\exp\left(-\frac{\frac{V_1}{V_2} + 1}{RV_1}\, t \right) - 1 \right] \right\}. \qquad (3)$$

For values of R, V_1, and V_2 likely to pertain to apparatus such as that of Fig. 1, the exponential becomes insignificant after 20 sec or much less. Equation (3) then reduces to

$$P_2 = \frac{L}{V_1 + V_2} \left[t - \frac{RV_1}{\frac{V_1}{V_2} + 1} \right] \qquad (4)$$

Now, $[L/(V_1 + V_2)]t$ is exactly the pressure that would be measured in the McLeod if no resistance existed between it and the Volume, as is assumed in the procedure. The error in the determination of leak rate is, then, given by the second expression in the brackets. Evaluation of this expression leads to the error figures cited in Ref. 2.

APPENDIX 6

Work Plan

Contract NAS3-26611

Fiber Optic Cable Feedthrough and Sealing

Work Plan

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18 April 1992

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TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

The operational performance of a Fiber Optic system is a subject receiving substantial current attention because of the complexities of sensors used in the system and harsh environments encountered by the Space Shuttle Main Engine. A second phase which will require further development testing and produce working feed-through units is necessary to expand the successful findings of Phase I. Results of phase I show that there are materials and designs which will provide improved feedthrough units for NASA use.

This follow-on Phase II program will more fully develop and improve fiber optic hermetic sealing capabilities and provide a complete working fiber optic cable feedthrough for the NASA cryogenic liquid propulsion system environment. This includes design, development, fabrication and testing of new prototype feedthroughs and backshells.

The effort will be directed toward the full development of a fiber optic cable feedthrough and sealing to provide efficient performance, light weight, reliability, ruggedization, and high and low temperature sustaining characteristics. Evaluation of optical signal performance through a developed feedthrough will be accomplished from ambient end into cryogenic environment.

Under NASA sponsorship, LiteCom for the past 6 months (Phase I fiber optic cable feedthrough and sealing program) has been conducting analytical and experimental studies on fiber optic components. These studies have been aided greatly by the use of LiteCom's extensive Electro-Optical laboratory facility.

The material which follows includes a narrative of the technical approach of Phase II. Also presented is a summary of operations information which indicates the technical basis of LiteCom's operations, program management and an overview of scheduling for the contract effort.

2.0 TECHNICAL OBJECTIVES

The objective of this program is to develop, test, evaluate, and deliver a fiber optic feedthrough and sealing device which is hermetically sealed and can be used on a rocket engine controller interface.

2.1 SPECIFIC OBJECTIVES FOR PHASE II

Based on the feasibility study carried out during the Phase I effort, the following are anticipated for Phase II:

2.1.1 Further development and refinement of sealing material to provide a comprehensive fiber optic feedthrough for a cryogenic liquid propulsion system environment.

2.1.2 Further development of a feedthrough which can be relatively simple to install with easy-to-use assembly procedures.

2.1.3 Further development of backshell techniques that can be applied to improve ruggedization through use of the new fiber optic feedthrough system. Optional configuration straight and right-angle backshells will be fabricated.

2.1.4 Evaluation of the performance of the feedthrough with various fibers selected for their environmental, mechanical, temperature, and radiation-resistant characteristics.

2.1.5 Comprehensive evaluation of the available optical fibers, fiber coatings, fiber optic cables and appropriately rated accessory backshells for NASA SSME applications. This involves extensive testing beyond preliminary testing reported in the Phase I effort.

2.1.6 Performance of in-house tests for evaluation of feedthrough fiber backshells in the laboratory.

2.1.7 Performance of extensive high temperature, cryogenic and vibration environmental testing for feedthroughs and sealing on the most adverse environment-resistant fibers.

2.1.8 Development of a final feedthrough system design and performance specification that will incorporate the results of the findings of the Phase II project.

3.0 TECHNICAL APPROACHES

In order to achieve the objectives in Section 2.0, the following detailed approaches will be implemented.

3.1 Further Investigation and Development of Optimum Feedthrough Sealing Material.

Preliminary investigation performed during Phase I of the program has shown the capabilities of the proposed new polycrystalline and zircon silicate base sealing material for the fiber optic feedthrough in cryogenic liquid propulsion system environment. Further development of best sealing preparation techniques for the optimum fibers are required. The objectives of this Task are (a) to resolve issues associated with the sealing material in accelerated vibration, thermal cycling and radiation environments, and (b) to use the most harsh environment resistance optical fibers for independent verification of the insertion loss through complementary techniques. Testing details are discussed in section 3.4 and 3.5.

This will provide further enhancement of the performance and the reliability of the fiber optic feedthrough unit. A written report containing the results of this work will be submitted to NASA for review and approval at the conclusion of this task.

3.2 Further Design and Development of a Fiber Optic Feedthrough which can be relatively simple to install with easy-to-use assembly procedures.

Using the polycrystalline and zircon silicate materials, feedthrough units will be constructed.

These feedthrough units will be fabricated with a plurality of different fibers, will be ruggedized and will be full-working units. Evaluation of relative performance with the different fibers is anticipated to result in final recommendations for the optimum design of feedthrough units.

Feedthrough units will be built with single channel and multi-channel configurations. Assembly procedures for installing the actual feedthrough unit on a bulkhead panel will be developed for simplicity of technical expertise required and minimum specialized tooling needed.

(a) Evaluation of the performance of the feedthrough units will be accomplished with various fibers selected for their environmental, mechanical, temperature, and radiation-resistant characteristics.

Phase I evaluation included investigation of the suitability of several candidate fibers for space feedthrough applications. The recommendations of Phase I narrowed the field to polyimide, aluminum-coated and titanium carbide (TiC) coated fibers. These were all 100/140 glass/glass fibers with the appropriate special coating.

In Phase II, the construction of feedthrough units will be made using all of these candidate fibers for testing the relative merits of each type of feedthrough under the proposed testing. (see 3.4, 3.5). The units will also be fabricated with the two sealing materials described in 3.1 making a total of 6 different feedthrough types to be evaluated. (3 fibers, 2 sealing materials).

(b) Evaluation of fibers, coating, cables, backshells for feedthrough.

The prototype units will be built using combinations of various fibers (coating), cable constructions (strength members, jacketing) and backshells. These feedthrough units will be tested in entirety to evaluate them as complete units, beyond the testing/evaluations of the individual component elements. Extensive testing of the conditions shown in 3.4 and 3.5 will be conducted.

3.3 Further Development and Fabrication of Accessory Backshells that can be used to Improve Ruggedization of the new Fiber Optic Feedthrough System.

In Phase I, backshells were designed to ruggedize the cable entry/feedthrough transition. The design of straight and right-angle backshells are shown in the Phase I report. These will now be fully detailed to enable fabrication. Units built will be used on the feedthrough which are submitted to testings.

Both straight and right-angle backshells will be fabricated and tested to verify acceptable performance under vibration, temperature/pressure differential and radiation testing described in 3.4. and 3.5.

Backshells will be constructed for single and multi-channel applications, for straight and right-angle configuration for fiber optic ruggedized cable. Assembly techniques for backshells designed for ruggedized cable termination will be developed to minimize technical expertise and special tooling required.

3.4 Tests and Evaluation

The series of in-house tests were performed during Phase I of the project. These tests were limited to the evaluation of the fiber optic components with regard to temperature. It is proposed that a more comprehensive series of tests be performed in order to evaluate the performance of components. This includes testing the fiber optic feedthrough, sealing material, fiber, cable and backshell. The range of test conditions of fiber optic components, will be as follows:

(1) Temperature range, cryogenic to high temperature -320°F to the maximum temperature the fiber can withstand up to 2000°F. The limitation is anticipated to be the fiber. This will be evaluated.

(2) Vibration levels, 40 g at 10-3000 Hz random.

(3) Pressure differential levels applicable to space environment. (Helium leak rate testing for feedthrough).

(4) Insertion loss test (Figure 1 shows the test set-up).

The purpose of these tests is (a) to produce a realistic environment, (b) in which to determine the attenuation of the fiber optic cable feedthrough to be used in the SSME; (c) to determine the practical aspects of using fiber optic cable feedthrough and sealing techniques in the presence of cryogenic liquid propulsion system environments.

The details of the test program will be provided to NASA for approval. A written report describing the tests will be prepared and submitted to NASA for review and approval.

3.5 Radiation Hardening Test

Extensive communication between LiteCom and Rockwell have taken place during the first Phase of the project. It has been determined that in order to establish the applicability of the proposed concepts, there must be radiation resistant components for fiber optic feedthrough in radiation exposure environment. It is necessary that a series of verification tests be carried out. This must be conducted in a realistic yet controlled environment. The radiation Hardening Test Facility at Rockwell (^{60}Co located in Canoga Park and Flash x-ray machine located in Anaheim) will be utilized. It is proposed that a series of tests, over approximately three weeks, be performed in a test chamber. Figure 1 shows the test set-up and Figure 2 shows radiation hardening test levels.

It is expected that the results of these tests will be used to establish the merits of the most radiation resistant fiber optic feedthrough elements.

The details of the test program will be provided to NASA for approval. A written report describing the tests will be prepared and submitted to NASA for review and approval.

3.6 Develop Final Feedthrough System Design and Performance.

A final specification will be developed outlining the material to be used in construction of the feedthrough (sealing materials, fibers, housings) and the physical design of the units. Attention will be given to the various backshell options recommended and the assembly/installation procedures both for installing the feedthrough on a panel/bulkhead and for installing the cable strength member jacketing to the rear of the accessory backshell. Backshell construction and materials will be specified.

Test results will give direction to the specification requirements presented in mechanical (vibration) and environmental (temperature, pressure-differential, radiations) conditions.

Fiber and cable construction will be presented in the system specification. This includes descriptions of materials and dimensions of the fibers, buffer, coating, strength member, cable jacketing.

4.0 OPERATIONS

4.1 Past Performance Record

LiteCom personnel have for many years been active in designing and developing fiber optic components and systems for military applications. This background experience qualifies LiteCom participating personnel to be involved with current laser/optics systems sensor controls and component improvement of design, development and testing. Considerable experience in related military and commercial fiber optic interconnections, splices and couplers is part of the background of LiteCom personnel. Active transducers and electro-optic elements have been designed in the past by LiteCom personnel.

4.2 Qualifications of Key Personnel

The proposed principal investigator, Dr. Robert Fan, has been involved for fourteen years in the fiber optic component and system designs. In particular, he has worked on the research and manufacturing fabrication Technique for Fiber Optic Multiplexers, Single/Multi Mode Fibers, Fiber Optic Sensors, Fiber Optic Splicing Device, Fiber Optic Couplers and Connectors, Fiber Optic Feedthrough, Solving back reflection problems on a 3M fiber optic equipments, Radiation Hardness for Fiber Optic Systems, Polarization Maintaining Fiber-based (PONDA fibers) two-component Laser Doppler Velocimeter for application in the Aerospace, Fiber optic high energy (0.5 joules) transferred system in the SICBM and HML program, Fiber Optic Sensors for detection of Sodium Leak from Pool-Type Liquid Metal Cooled Reactor Vessel for GE Nuclear Energy, design and development of Pulsed Laser

Holographic System and fiber optic size 16 lens termini development for SEM, Naval Avionics Center.

In addition, he has developed a MIL-STD-1760 electrical interface connector with provision for size 16 fiber optic termini. Complete terminus development including preparation tooling was accomplished by Dr. Fan for size 12 and size 16 termini for use in MIL-C-38999 Series I, III and IV connectors. Development included backshell accessories.

In addition to Dr. Fan, Mr. Douglas Parker, Mr. Robert Briggs, and Dr. Wang will contribute to the proposed program. Mr. Parker is a specialist in the field of fiber optic connectors and was Chairman of EIA/TIA Fiber Optic Field Tooling and Test Instrumentation FO-6.1 Working Group from inception (1982) to 1989. He will be involved in the mechanical feedthrough and backshell design in the proposed study.

Mr. Parker has accomplished design, fabrication and testing efforts of prototype and finalized commercial/military fiber optic size 16 termini and interchangeable short-profile RF size 16 contacts plus size 20 fiber optic termini for the SEM-C Configuration. The Standard Electronic Modules (SEM) of the Standard Hardware Acquisition and Reliability Program (SHARP) are widely used for high density electrical interconnects in card-edge-to-backplane interfacing. As a portion of that Navy effort, Naval Ocean System Center (NOSC) and Naval Avionics Center (NAC) are coordinating fiber optic SEM applications development. In addition, he has developed a MIL-STD-1760 electrical interface connector with Dr. Fan.

Mr. Briggs has been working in the communications field all his career. He has work in data communications on satellites and fiber optic projects. For the past twelve years he has been directly involved in research and development projects in the communication discipline. He will be involved in the implementation of fiber optic feedthrough testability in the proposed study.

Dr. Wang has extensive experience in a number of areas involving fluid flow and heat transfer. In the area of aerodynamics, he has improved and utilized design-type supersonic-hypersonic aerodynamic computer codes, applied shock capturing numerical methods to hypersonic flow around bodies of elliptical cross section, and investigated vortical flow around delta wings at high angles of attack. In addition, he has carried out extensive experimental research on the effects of curvature on turbulent mixing layers formed by gases of dissimilar densities, has performed experiments on flow around blunt bodies using a laser Doppler velocimeter (LDV) system in a water tunnel, and has developed new methods of forced cooling for heavily insulated high-temperature furnaces.

4.3 Personnel Assignment

Figure 3 depicts the program organization for the fiber optic cable feedthrough and sealing program. Robert Fan has been selected as Program Manager. Robert Fan has several years experience in the development of state-of-the-art fiber optic components. Robert Fan will be Principal Investigator for the sealing material design and analysis. Mr. Douglas Parker will be Principal Investigator for fabrication and assembly, and backshell design modification tasks. Mr. Briggs will serve as Principal Investigator under tests and evaluation tasks. Ms. Linda Fan will be Principal Investigator for the feedthrough design, and feedthrough cable system analysis tasks. Finally, Dr. Chiun Wang will serve as Principal Investigator under the cable feedthrough system specifications task. All of the Principal Investigators were chosen based on their experience in the respective task disciplines. Moreover, Mr. Parker, Mr. Briggs and Dr. Wang have worked closely with Robert Fan on previous programs, and a good relationship has been established.

4.4 Facilities and Equipment.

Facilities that will be utilized under this program include LiteCom's optical/electronic laboratory, located in Canoga Park, California, the Department of Mechanical Engineering (M.E.) Vibration laboratory at California State University-Long Beach (CSULB) located in Long Beach, California and National Technical Services in Saugus, California. Available equipment and materials at LiteCom include a variety of lasers (He-Ne, and 850 nm, 1300nm and 1550 diode lasers and light sources(UV, IR and visible), optical benches, optical components, fiber optic related products, and cryogenic test tank. Six varieties of detectors and measurement instruments. Supporting this laboratory are PC, CAD systems, and data-management software. LiteCom's recently expanded 2000 Square feet facility is dedicated to fabrication and production of special purpose fiber optic components, units and systems.

The facilities and equipment of CSULB will be used in connection with Task 6 and 7.

The items required for the tests and fabrication of the feedthroughs, sealing materials and fiber evaluation are listed in the cost proposal. They include parts which are needed for testing, fabrication and the instruments for in-house tests as well as tests at CSULB and Rockwell.

It is not anticipated that any test equipment will be purchased or be required as furnished by the government to fulfill Phase II efforts.

Items specifically used in the design of the fiber optic feedthrough including the yttia zirconia material and special adverse environment fiber optic cables will be purchased. Machining of the parts will be performed at a local precision machine shop.

The facilities and equipment of CSULB will be used in connection with mechanical testing, and the thermal testing will be performed at NTS.

The LiteCom team will procure all components and materials and perform necessary fabrication. This includes the feedthrough, prototype backshells and optical fiber/cable. These components will be assembled for testing and on-site review including a demonstration of the system, which will be presented to NASA personnel.

4.5 STATEMENT OF WORK

4.5.1 OBJECTIVE

The objective of this program is to develop, test, evaluate, and deliver a fiber optic feedthrough and sealing device which is hermetically sealed and can be used on a rocket engine controller interface.

4.5.2 SCOPE OF WORK

The contractor (LiteCom) shall deliver a hermetically sealed, fiber optic feedthrough assembly which is capable of operating in an environment characteristic of a rocket engine controller. Suitable component materials and designs shall be chosen based on Phase I results, and on subsequent testing as determined necessary. Assemblies shall be fabricated with suitable components and subjected to environmental and performance testing.

4.5.3 TECHNICAL TASKS

4.5.3.1 Task I - Further development and refinement of the sealing concept.

The contractor (LiteCom) shall determine the best possible suitable optical fibers and sealing materials, based on Phase I results and supplemental testing, for the fiber-optic feedthrough. Suitability shall be determined based on the following criteria:

(1) Ability to operate in the environment specified by the following engine controller connector specifications for the Space Shuttle main engines:

(a) -250F to +392F operating temperature

(b) 20 to 2000 hz vibration and shocks to 40Grms

(c) ambient pressure to vacuum

(d) salt, air, and 100% humidity

(2) Ability to withstand long duration exposure to space radiation without significant degradation of performance.

(3) Capability to provide minimum insertion loss. Criteria for minimum insertion loss shall be determined by the contractor (LiteCom) with respect to current feedthrough capabilities.

(4) Ability to provide a hermetic seal. Criteria for hermeticity shall be determined by the contractor (LiteCom) with respect to current feedthrough capabilities.

Tests shall be performed, as needed, to help determine the suitability of candidate optical fibers and sealing materials, and combinations thereof. Tests shall not be performed on fibers and materials already determined unsuitable based on the above criteria.
A written report containing the results of this selection shall be submitted to NASA for review and approval at the conclusion of this Task I.

4.5.3.2 Task II - Further development of fiber optic feedthrough design

The contractor (LiteCom) shall complete the design of the fiber optic feedthrough. All components will be specified and engineering drawings of the components to be fabricated shall be prepared. The final design drawings and specifications shall be presented to NASA for review and approval at the conclusion of Task II, before fabrication.

4.5.3.3 Task III - Further development of backshell designs.

The contractor shall complete the design of the fiber optic backshells. One final design for a straight backshell and one final design for a right-angle backshell shall be completed. All components will be specified and engineering drawings of the components to be fabricated shall be prepared. The final design drawings and specifications shall be presented to NASA for review and approved at the conclusion of Task III, before fabrication.

4.5.3.4 Task IV - Fabrication and Assembly

The contractor shall procure all necessary components and materials and perform necessary fabrication. This includes the feedthroughs and prototype backshells with fibers and sealing materials which were determined suitable in Task I. The feedthroughs and backshells shall be assembled for testing and review which include an on-site demonstration of the feedthrough system presented to NASA upon completion of the task.

4.5.3.5 Task V - Tests and Evaluation

The feedthrough assemblies, which include a backshell and feedthrough with appropriate sealing materials and optical fibers, shall be subjected to the following tests:

(1) Cryogenic temperatures at or below -320F for a suitable duration as determined by the contractor and approved by the NASA project manager.

(2) High temperatures at or above +392F for a suitable duration as determined by the contractor and approved by the NASA project manager.

(3) Vibration testing from no more than 20hz to no less than 2000 hz and shock testing equal to or greater than 40G's.

(4) Helium leak rate testing at a pressure differential indicative of a space environment.

(5) Measurement of insertion loss and evaluation of these results.

Upon completion of the above tests, feedthrough assembly prototypes shall be evaluated. Only those assemblies which are determined to have passed these tests shall be subjected to the tests described in Task VI.

4.5.3.6 **Task VI - Radiation Hardening Test**

The contractor shall formulate a test program to evaluate the feedthrough assemblies which are determined suitable through Task V in the Radiation Effects Laboratory identified in the Phase II proposal. After review and approval by NASA, the contractor shall carry out this test program. A written report describing the tests, the results of these tests, and the associated evaluations and recommendations shall be prepared and submitted to NASA.

4.5.3.7 **Task VII - Fiber optic cable feedthrough system specifications and reporting requirements**

The contractor shall prepare a comprehensive and final specification and performance profile, and deliver this document and the final feedthrough assembly to NASA upon completion of the program. The contractor shall perform technical, financial, and schedular reporting in accordance with Section F of this contract.

4.6 TASK ORGANIZATION

The task organization for the Fiber Optic Cable Feedthrough and Sealing program is given in Figure 4.

4.7 TASK SCHEDULES

The schedules for the tasks under the Fiber Optic Cable Feedthrough and Sealing Program are given in Figures 5 and 6.

4.8 DELIVERABLES

Deliverables for the fiber optic cable feedthrough and sealing program include:

* Monthly Progress Reports
* Monthly Cost Performance Reports
* Work Plan
* Test Requirements Document
* Test Reports
* Scientific And Technical Operating Report/Final Report
* Prototype Feedthrough
* Prototype Backshell

* Cable Assembly

4.9 PROGRAM MANAGEMENT

LiteCom technical personnel have long-standing involvement in the field of fiber optics. Key management personnel assigned to this program are highly skilled with experience in areas such as optical sensor techniques, fiber optic techniques, electro-optic research and instrumentation development which are directly applicable to the contract effort. LiteCom has dedicated the facilities required to meet the objectives of the program.

Key management will maintain records, monitor contract progress and interface with NASA to assure fulfillment of all contract milestones and obligations.

4.9.1 Program Organization

The fiber optic cable feedthrough and sealing is managed and performed with personnel from the LiteCom technical group carrying out contract requirements.

Program tasks and their responsible managers are shown summarized in the organization structure, Figure 3. Robert Fan has been selected as principal investigator and program manager with periodic technical reviews to be provided by Mr. Douglas Parker, Mr. Robert Briggs, Dr. Chiun Wang, Ms. Linda Fan, and Ms. Jeh-Wah Lee.

4.9.2 Program Management Approach.

LiteCom's management approach is based on both technical and project control considerations. Key technical features include:

* A program organization tailored to specific task requirements with controlled milestone timing of the tasks.
* Experienced team members.

The LiteCom Performance Measurement System (PMS) is the basis for project control on the program. Key features of PMS are:

* Disciplined project planning.
* Cost, schedule and technical baseline for designing performance.
* Monthly reports reflecting progress versus plan and earned value.
* Analysis and reporting variances from performance baseline.

Important aspects of PMS include:

4.9.2.1 Organizing the Work

The Work Breakdown Structure (WBS; e.g. Figure 4) defines project activities and is the frame work for assigning project work and authority, collecting costs, and monitoring schedule, controlling cost and monitoring technical performance. For each level of the WBS, work items are defined by task descriptions, associated schedules, and performance measurement budgets. The information is used to prepare the Summary Task Planning Sheets and the Project Work Authorization.

4.9.2.2 Scheduling, Budgeting, and Controlling

In accordance with the WBS, the Program Manager issues a Project Work Authorization (PWA) to the performers for all work to be performed, thus providing an accurate trace of how the expenditure of each dollar on the program was authorized. As a minimum, a PWA must describe the work to be done, contract WBS element or summary tasks affected, technical characteristics or constraints imposed, schedule for accomplishing the work, authorized budget, and any special administrative information.

Figure 7 depicts the project Milestones and Reporting Schedules. In addition, a schedule of proposed Technical Interchange meetings at six-month intervals is included.

4.9.2.3 Reporting, Work Assessment and Review

The Program Manager is using mandatory project review, informal coordination meetings, and bi-weekly and monthly progress reports to monitor technical cost and schedule status. Day-to-day liaison identifies action items and their priorities; clarifies work objectives; solves interface problems and provides the Project Manager with information to take corrective action when needed. At the management review meetings, each person at each level of responsibility must present his cost, schedule and technical status to the next level of supervision. He must explain all problems or anomalies and raise questions or special subjects for review.

4.9.3 Man-Loading Schedule

Figure 8 depicts the project summary by tasks. A man-loading schedule by task, labor category, and month is given in Figure 9. In addition, the man-loading for the total program is shown.

4.9.4 Manpower Loading By Dollars

Manpower loading schedule by dollars, task, labor category, and month is given in Figure 10.

4.9.5 Costing Summary

Figure 11 depicts the costing summary. Costing schedule by task, labor category, and dollars are given in Figure 12.

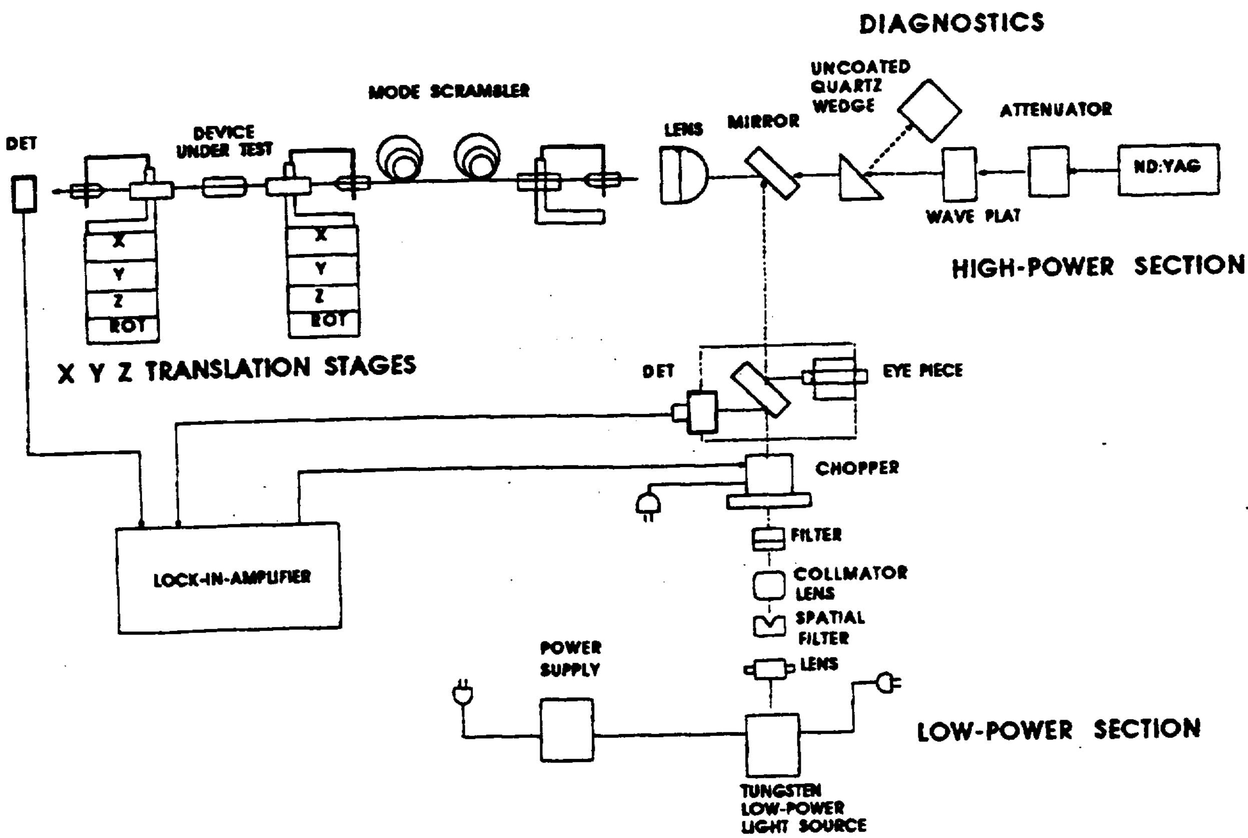

Figure 3. Fiber Optic Test Set-Up for Low and High Energy Testing.

SYSTEMS REQUIREMENTS

Test Criteria, Nuclear Hardening

SYSTEM	QUANTITY	n/cm^2		Rads(Si)/sec		Rads(Si)	
		RANGE	TEST LEVEL	RANGE	TEST LEVEL	RANGE	TEST LEVEL
Aircraft	20	$10^9 - 10^{14}$	10^{12}	$10^6 - 10^9$	10^9	$10^2 - 10^4$	10^3
Ship	15	$10^{11} - 10^{12}$	10^{12}	$10^7 - 10^{10}$	10^9	$25 - 10^4$	3×10^3
Ground	15	$10^9 - 10^{13}$	10^{12}	$10^7 - 10^{10}$	10^9	100 - 7500	3×10^3
Missile	8	$10^{12} - 10^{14}$	10^{12}	$10^9 - 10^{12}$	10^{12}	$1500 - 5 \times 10^6$	10^5
Space	14	$10^{11} - 10^{14}$	10^{12}	$10^{10} - 10^{12}$	10^{12}	$3000 - 10^6$	10^6

Figure 2. Systems Requirement, Test Criteria, Nuclear Hardening

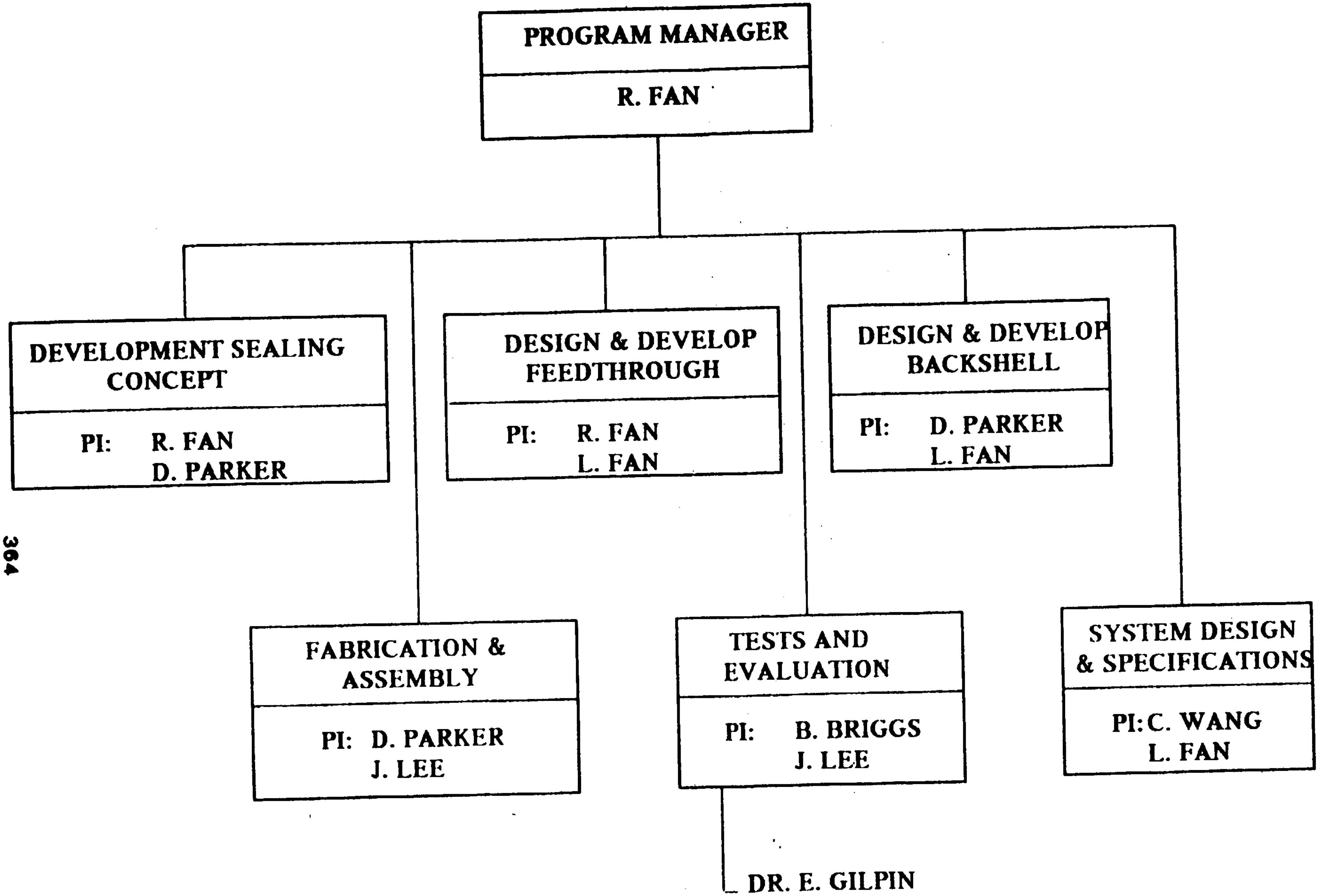

Figure 3. Project Organization

- **FIBER OPTIC CABLE FEEDTHROUGH & SEALING**
  - **TASK 1 — SEALING CONCEPT**
    - 1.1 ASSESS & DESIGN
    - 1.2 FIBER ANALYSIS
    - 1.3 SEALING MATERIAL SEARCH
    - 1.4 MOCKUP TEST
    - 1.5 RECOMMENDATION
  - **TASK 2 — FEEDTHROUGH**
    - 2.1 DEVELOP SEALING MATERIAL
    - 2.2 FEEDTHROUGH DEVELOPMENT
    - 2.3 FABRICATION & ASSEMBLY
    - 2.4 TESTS & EVALUATION
  - **TASK 3 — BACKSHELL**
    - 3.1 ANAL. & DESIGN
    - 3.2 FABRICATION & ASSEMBLY
    - 3.3 TESTS & EVALUATION
  - **TASK 4 — RADIATION HARDENING TEST**
    - 4.1 DESIGN & DEVELOP TEST SETUP
    - 4.2 FABRICAT. & ASSEMBLY
    - 4.3 TESTS & EVALUAT-ION
  - **TASK 5 — MANAGEMENT & DOCUMENTATION**
    - 5.1 MANAGE-MENT
    - 5.2 DOCUMEN-TATION

Figure 4. Task Organization

Project: Fiber Optic cable feedthrough and sealing

TASKS I TO III

PERT Chart

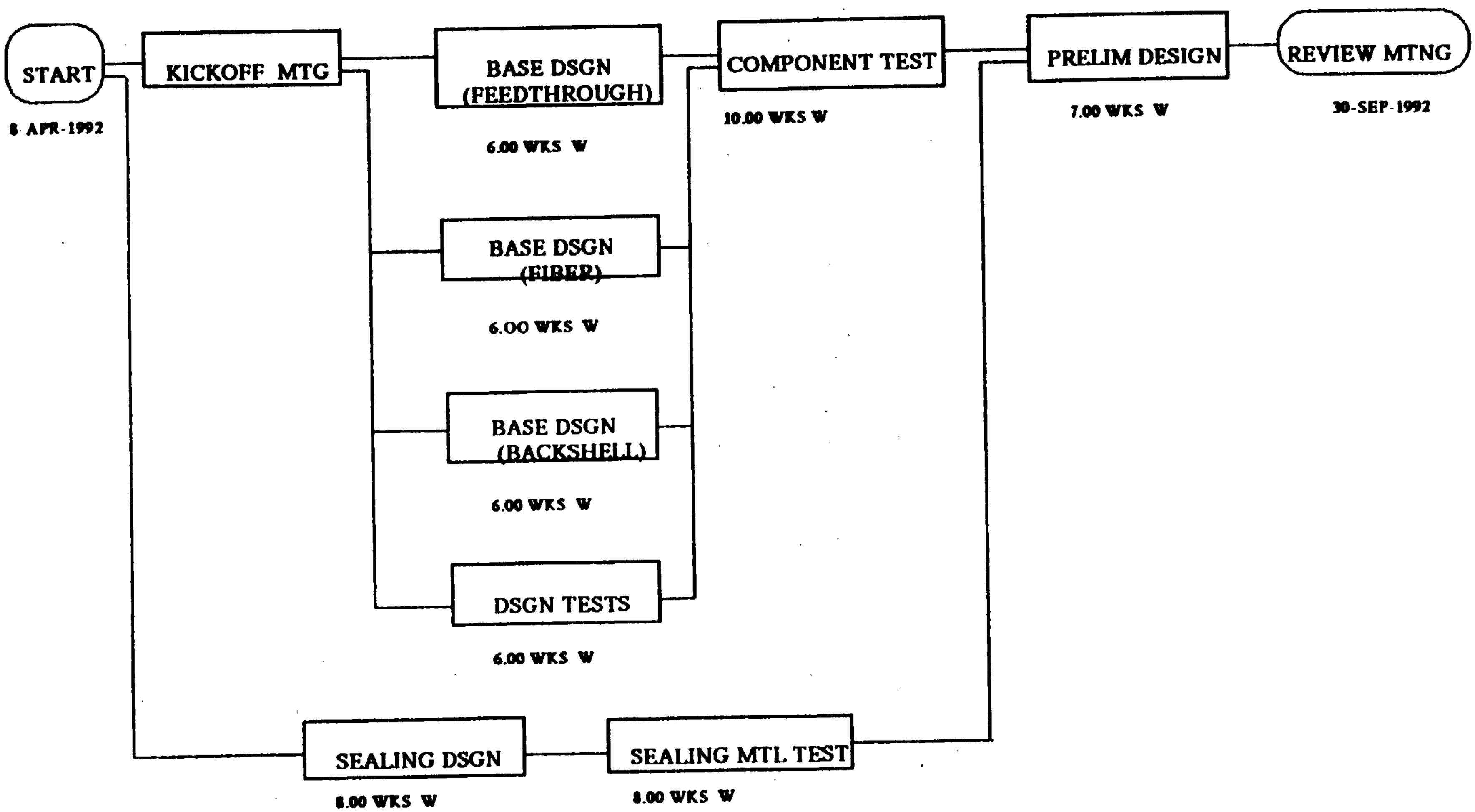

Figure 5. PERT Chart for Tasks I to III

Project: Fiber Optic Cable Feedthrough and Sealing

TASKS IV TO VIII

PERT Chart

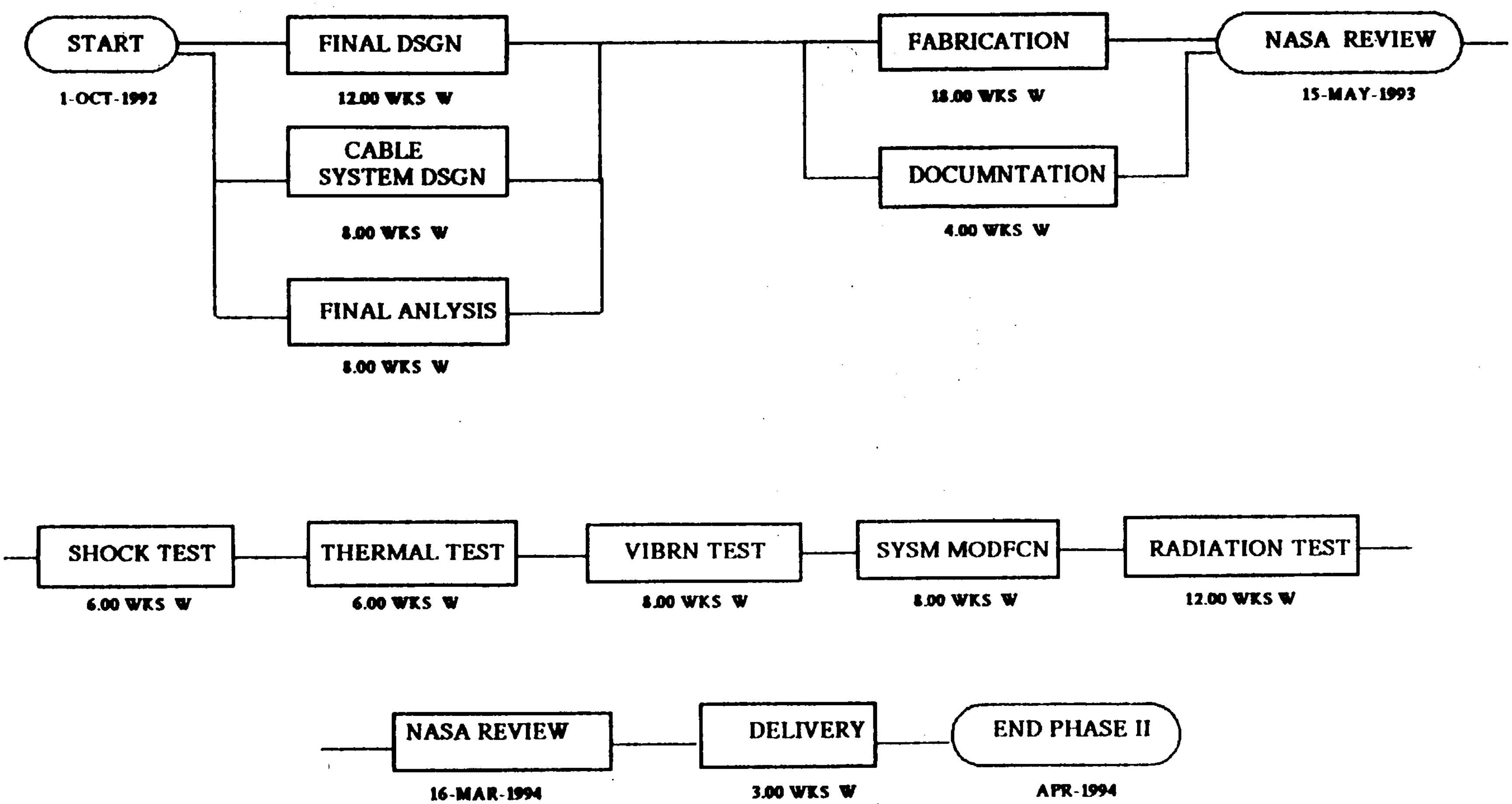

Figure 6. PERT Chart for Task IV to VIII

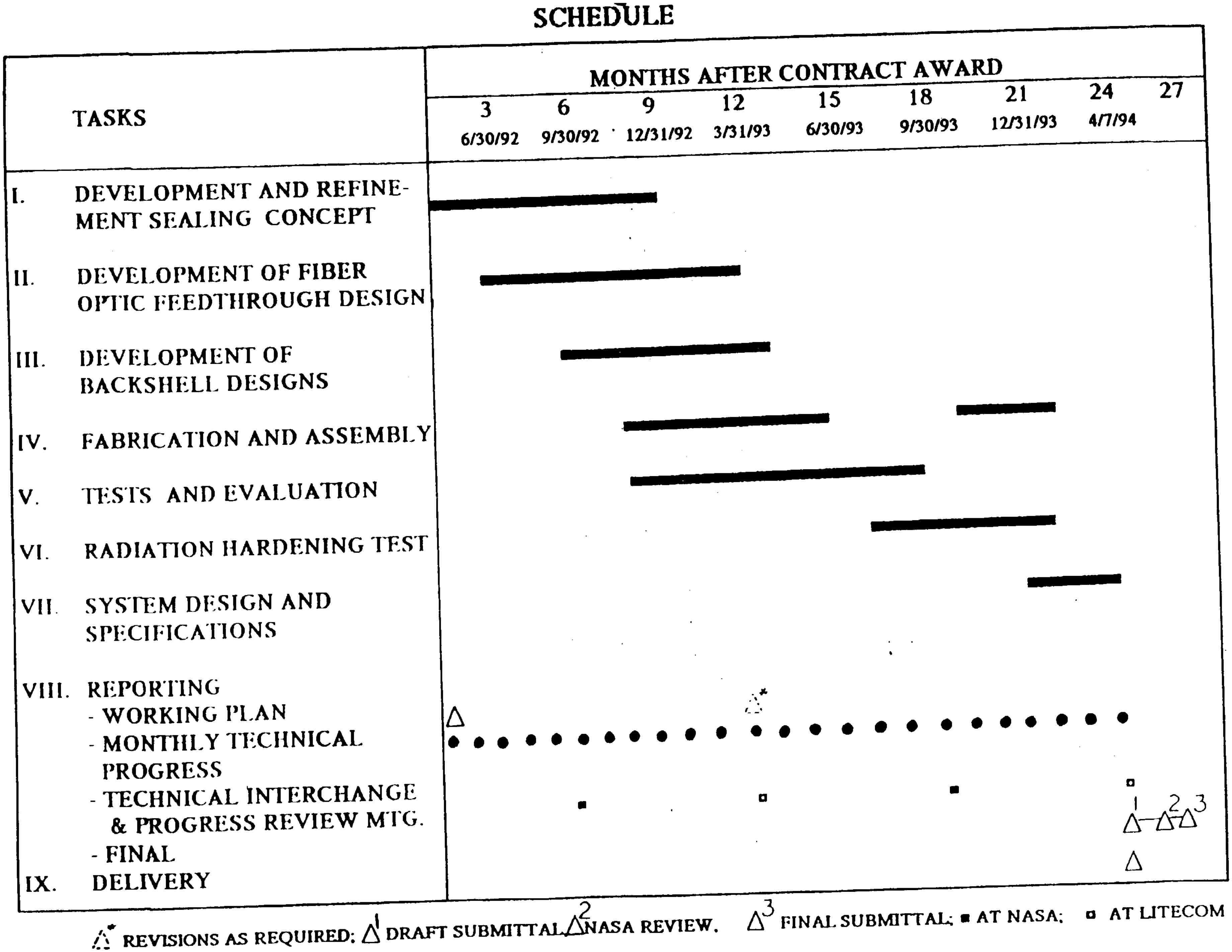

Figure 7. Schedule

APPENDIX 7

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APPENDIX 8

Glossary of Fiber Optic Terms

GLOSSARY

Avalanche Photodiode (APD): A photo-detecting diode that is sensitive to incident photo energy by increasing its conductivity by exponentially increasing the number of electrons in its conduction-band energy levels through the absorption of the photons of energy, electron interaction, and an applied bias voltage. The photodiode is designed to take advantage of avalanche multiplication of photocurrent. As the reverse-bias voltage approaches the breakdown voltage, hole-electron paris when they collide with substrate atoms. Thus, a multiplication effect is achieved.

Cable Assembly: A cable terminated and ready for installation...

Coherent Light: Light that has the property that at any point in time or space, particularly over an area in a plane perpendicular to the direction of propagation or over time at a particular point in space, all the parameters of the wave are predictable and are correlated...

Feedthrough: Controlled penetration of a sealed bulkhead panel separating the boundary between two potentially different pressure/temperature zones.

Fiber Absorption: In an optical fiber, the light-wave power attenuation due to absorption in the core material, a loss usually evaluated by measuring the power emerging at the end of successively shortened known lengths of the fiber.

Fiber Buffer: The material surrounding and immediately adjacent to and optical fiber that provides mechanical isolation and protection. Buffers are generally softer materials than jackets.

Fiber Cladding: A light conducting material that surrounds the core of an optical fiber and that has a lower refractive index than the core material.

Fiber Core: The central light-conducting portion of an optical fiber. The core has a higher refractive index than the cladding that surrounds it.

Infrared (IR): Electromagnetic radiation in the range of frequencies that extends from the visible red region of the spectrum to the microwave region, the frequency being lower and the wavelength longer than that of visible red. The band of infrared electromagnetic wavelengths lies between the extreme of the visible part of the spectrum, about 0.75 microns and the shortest microwaves, about 1000 microns. The IR region is often divided as near infrared, 0.75 to 3 microns; middle infrared, 3 to 30 microns; and far infrared, 30 to 1000 microns. The sun, moon, earth, and all bodies having a temperature above absolute zero are sources of infrared radiation. Absorption of light energy in a transmission medium, such as an optical fiber or integrated optical circuit, can result in the production and dissipation of infrared radiation-namely, as heat, which may be removed by conduction, convection, of radiation.

Insertion Loss: In light-wave transmission systems, the power lost at the entrance to a waveguide, such as an optical fiber or an integrated optical circuit, due to any and all causes....

Interference: In light wave transmission, the systematic reinforcement [and/or] attenuation of two or more light waves when they are superimposed. Interference is an additive process. (The term is applied also to the converse process in which a given wave is split into two or more waves by, for example, reflection and refraction at beam splitters.) The superposition must occur on a systematic basis between two or more waves in order that the electric and magnetic fields of the waves can be additive and produce noticeable effects such as interference patterns. For example, the planes of polarizations should nearly or actually coincide or the wavelengths should [be] nearly or actually...the same.

Laser Firing Unit Harness: Fiber optic cable/connector branch-out configuration for monitoring/reaching all required locations in the laser ordnance system.

Optical-Fiber Coating: A protective material bonded to an optical fiber, over the cladding in any, to preserve fiber strength and inhibit cabling losses, by providing protection against mechanical damage, protection against moisture and debilitating environments, compatibility with fiber and cable manufacture, and compatibility with the jacketing process. Coatings include fluorpolymers, Teflon, Kynar, polyurethane, and many others....

Single-Mode Fiber: A fiber waveguide that supports the propagation of only on mode. The single-mode fiber is usually a low-loss optical waveguide with a very small core.... It requires a laser source for the input signals because of the very small entrance aperture (acceptance cone). The small core radius approaches the wavelength of the source; consequently, only a single mode is propagated. [Mode is, in simple terms, the path of an optic ray.]

Termini: Optical fiber end termination as defined in DOD-STD-1864. Differentiated from electrical contact.

Transmittance: The ratio of the flux that is transmitted through and object, to the incident radiant or luminous flux. Unless qualified, the term is applied to regular (i.e., specular) transmission....

Ultraviolet Fiber Optics: Fiber optics involving the use of ultraviolet (UV) light-conducting components designed to transmit electromagnetic waves shorter in wavelength than the waves in the

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13. ABSTRACT ***(Maximum 200 words)***
A novel fiberoptic hermetic bulkhead feedthrough has been developed which will offer cryogenic sealing at leak rates of 10^{-11} cc/sec helium. This feedthrough was developed for NASA in response to needs for a hermetically sealed feedthrough which could withstand a range of temperatures from low cryogenic (–196°C), due to liquid fuels and oxidizers, to high temperatures (+200°C) encountered in the proximity of combustion gasses. The development effort will be reported from conceptual design of single and multi-channel feedthrough units with single interconnection interfaces to units with double-ended interconnection interfaces. Various combinations of fiber/buffers are reported with recommendations based on test results. A comprehensive series of environmental and mechanical tests were performed to evaluate the feedthroughs in adverse conditions. Test results are reported including insertion loss, salt spray, sinusoidal vibration, random vibration, mechanical shock, thermal shock and humidity. A second set of feedthrough units was exposed to 3 different types of radiation. Optical transmittance changes during the tests were monitored and leak rate testing was done after each test. State-of-the-art technology in optical fiber feedthroughs constructed with polycrystalline ceramic is presented.

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visible region of the spectrum. Primary applications include medical technology, medicine, physics, materials testing, photochemistry, genetics, and many other fields. Optical fibers with high UV transmittance have been developed and are being used.

Wavelength Division Multiplex (WDM): In optical communication systems, the multiplexing of light waves in a single medium such as a bundle of fibers, such that each of the waves is of a different wavelength and is modulated separately before insertion into the medium. Usually, several sources are used, such as a laser, or a dispersed white source, each having a distinct center wavelength. WDM is the same as frequency-division multiplexing (FDM) applied to other than visible light frequencies of the electromagnetic spectrum.